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Bulletin of Prosthetics Research

PROSTHETIC AND
SENSORY AIDS
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DEPARTMENT OF MEDICINE AND SURGERY
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". . . AND SENSORY AIDS"

. . . an editorial

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Past issues of the Bulletin have concentrated largely on prosthetics, with only brief mention of research on sensory aids in the notes on the VA Contractor Program. In this issue, for the first time, several major papers, in addition to progress reports, describe reading machines for the blind. Hopefully, future issues will be able to publish papers on further improvements—not only on reading machines for type but also for graphical material. From time to time, there also should be discussions of mobility aids for the blind, of magnifiers and other aids for the large numbers of partially sighted among the legally blind, and of hearing aids for the deaf and the hard-of-hearing.

There have been efforts on reading machines since the early years after the recognition of the photoelectric effect. A few machines, developed by outstanding scientists and engineers in several countries and at different times, reached precision construction and some degree of systematic trial. At the end of World War II, the National Research Council's Committee on Sensory Devices supervised an extensive government-financed effort at outstanding laboratories. To a generation accustomed to numerous marvels in other fields, though, the very limited progress on reading machines seemed so disappointing that there was little prospect for support of further research.

Disillusionment among scientists, government sponsors, and others in not reaching immediately the ultimate goal of an inexpensive, high-speed device to allow truly rewarding reading of long passages for great numbers of blind persons may well have led to frustration and overlooking of potentially useful methods suitable for prescription for small, carefully selected, highly motivated, and thoroughly trained segments of the blind population. As one blind man has written, even two words a minute would be infinitely faster than *he* could read!

In this issue our Electronics Engineer, Howard Freiberger, summarizes the Sixth Technical Conference on Reading Machines for the Blind. These meetings arose rather informally in 1954 because our office had found so

many friends who seemed to agree that the burgeoning technology and growing understanding of psychological principles allowed hope for independent reading by blind persons, in spite of repeated past disappointments.

Unhappily, in 1954 many of these more hopeful yet realistic friends of ours did not yet know each other, so we felt that some fostering of friendships and mutual widening of horizons through the conferences might be helpful. Some colleagues were pioneers in the then-visionary field of optical character recognition, others were psychologists or linguists interested in output problems, some were blind engineers themselves or experts in rehabilitation of the blind; all were convinced that something could reasonably be done to give blind people independent access to typed and printed information. Early conferences led to general agreement on a number of different approaches to specific goals, building on past knowledge, applying current technology and ingenious design engineering, and supporting basic and applied research in a variety of related fields.

Fournier D'Albe, the English physicist, just before World War I had worked on a relatively primitive machine which he described in various papers and in his book *The Moon Element, An Introduction to the Wonders of Selenium.* (It has seemed ironical that we have not again heard much about words derived from selene, the classical name for the moon, until the recent years of the space age, yet now a major factor in the currently renewed effort on reading machines is cadmium selenide, a compound of the "moon element.") Immediately after World War I, a production-engineered version of his optophone was built by Barr and Stroud, a well-known engineering firm in Great Britain.

Miss Mary Jameson, who as a blind girl had known Fournier D'Albe and had learned to use the early optophones, contributes a fascinating personal memoir of half a century of work on the problem of independent reading. She has demonstrated tremendous perseverance in struggling with technological inadequacies like horrible signal-to-noise ratios; some psychologists would insist that she has had to tolerate grossly inadequate output displays. All would agree she has patiently used the machines herself and has been a tireless missionary of the concept of making the typed or printed word available to those blind persons—few as they may be—who are *determined* to read in spite of frustrations.

Miss Jameson was almost a legend to some American workers for the blind in the era after World War II; they knew she replied to typed correspondence with touchtyped letters which occasionally carried postscripts apologizing for mistakes which she claimed to have detected with her optophone. To some cynics who "knew" that not even a skilled user could tolerate the very slow speed of the optophone—only a quarter of the speed with which many people typed letter by letter and far slower than the pace of the Talking Book—the notion of such specialized uses seemed ridiculous.

It was a pleasure, therefore, to visit Miss Jameson on many occasions, to verify her performance on everyday tasks, and to learn of her additional uses, such as reading hand-lettered block printing which a friend was sending to her on post cards. A tireless advocate of the optophone for selected users and uses, she had also taught a relatively few others in the British Isles—a teacher, a musician, and others. She used the optophone routinely in the course of her activities as honorary secretary of a group of blind. For many years she has been associated with the research program of St. Dunstan's, the organization for the British war-blinded. In recent years she has had the devoted help of Mr. W. Keith Hill in maintenance and improvement of her machines. On the walls of the room housing her optophone are her citation as a Member of the Order of the British Empire and recognition for declaiming of poetry at a contest. This charming, literate, motivated lady has long been willing to tolerate slow reading speed to achieve independence.

Curiously enough, sighted people tolerate writing at very much slower rates than we demand for speaking and especially for reading. Handwriting and typing are slow per se, and the overall rate for a business letter in words per man-minute expended, counting dictation, shorthand recording, transcription into typing, and proofreading, is very low indeed. Similarly, we do not expect a panacea-like solution in the design of writing instruments. Instead, we accept for specific tasks pocket pens, portable and office typewriters, and typesetting and printing machinery without demanding a single, inexpensive, portable device suitable for all writing tasks.

Shortly after World War II, the Veterans Administration organized a central rehabilitation center for blinded veterans at the VA Hospital, Hines, Illinois, a suburb west of Chicago. Drawing heavily on the staff, the consultants, and the experience of the outstanding Army program at Valley Forge and Avon in World War II, the Hines program achieved substantial success and set the pattern for increasing numbers of other centers. Quite understandably, the emphasis has been on the tried and proven techniques for mobility, communication, personal adjustment, vocational training, daily living, etc. The Hines center has taught a limited level of skill in braille to all patients for obviously valuable independent uses like reading labels on articles for the blind (e.g., Talking Book records) or privately labeling materials such as medicine bottles, canned goods, and boxes. This initial skill also served as a foundation for those (admittedly few) who chose to pursue braille skills toward the much higher speeds attained by students trained during childhood in schools for the blind.

Braille is excellent—when it is available, known, and accepted. Unfortunately, only a small fraction of the printed material readily accessible to the sighted population has been transcribed into braille; practically

none of the typed or duplicated material of limited but often important circulation is in braille. Relatively few blind persons are skillful in braille. As but one example, a study of recreational habits of blind persons showed that ony 28 percent claimed to know braille and only 7 percent drew as much as one braille book per year from the free circulating libraries sponsored through the Library of Congress and the state or local governments. Nevertheless, the Hines staff rightly recognized the importance of some acquaintance with braille for auxiliary uses even in the absence of rewarding reading speeds and skills suitable for prolonged reading of entire books.

In much the same spirit, Mr. Apple, the current chief of rehabilitation for visually impaired and blinded veterans at Hines, has perceived, as he tells us, the possible value of similar rudimentary skills with the very limited experimental reading machines which are beginning to emerge from the PSAS research program. He readily agreed to have Mrs. Miller of his staff trained as a teacher of the lengthy training course developed at Battelle Memorial Institute under VA auspices for its version of the optophone. Mrs. Miller initiated the training of Mr. Lauer, the blind braille therapist who describes so enthusiastically herein his later self-study program and further progress.

With the assistance of the Hines Orthopedic Brace Shop (another PSAS activity), Mr. Lauer also has developed a motorized tracking board and a carriage to assist in moving the Battelle probe over the line of print at uniform speed, extending ideas developed by Mr. Freiberger alone or with the assistance of the VA Prosthetics Center in New York. The favorable results of smoother pacing, long emphasized by Miss Jameson based on her experience with the Barr and Stroud precision apparatus, must be balanced against the somewhat greater complexity, weight, bulk, and cost of tracking aids. Some of us concerned with the restimulation of the optophone concept, in spite of the obvious and historically proven limitations of long training and inherently slow speed, have tended to stress the need for portability and simplicity in spite of the fact that unaided manual tracking forces further reductions in already limited speed. The *total* time to read a brief message, a check, a telephone number, or a label, or to identify paper money is mainly a function of availability and setup time of a reader, not so much of reading speed within the message.

The further miniaturization of the optophone principle exemplified in the Mauch Visotoner, using the same tone patterns as the Battelle, has been welcomed by Mr. Lauer. He has used the machine in its simplest hand-held form to read labels on packages in supermarkets and in similar tasks, supplementing more formal reading with the aid of the Colineator tracking device.

A device looking very much like the Mauch Visotoner is the Visotactor developed earlier at the same laboratory. Its tactile rather than audible

output is particularly suitable for use by deaf-blind persons, though it can be used by other blind persons. The Visotactor A was originally conceived primarily for carrying the more complex photocell array and supplementing the functions of the complete recognition reading machine for higher speed with spelled output which Mauch Laboratories hope to complete in future years. In the meantime, a blind subject has completed the 200-lesson Battelle optophone course using the simpler Visotactor B. She read adult material at over 7 words per minute at the close of the training series.

On this centenary of the birth of Anne Sullivan Macy, the famous teacher of Helen Keller, we are particularly reminded of the special problems of the deaf-blind. The Mauch Visotactor with tactile output was demonstrated privately to Robert Smithdas, the deaf-blind Handicapped American of the Year. Soon afterward the companion Mauch Visotoner with audible output was demonstrated by Mr. Lauer at the annual meeting of the President's Committee on Employment of the Handicapped. One can imagine numerous employment possibilities from such devices, limited though they inevitably are in speed, precisely because of their possibilities for independent and prompt deciphering of elusive, tantalizing inkprint and typescript—and engraving on paper money.

Evaluation is a difficult task at best. It can be further confused by misunderstandings of goal and by unrealistic minimum scores demanded for "success." A reading system requiring extensive training, demanding some manual skills, and used routinely by only a very small percentage is rightly recognized as of great value if it has a long, perhaps turbulent, but ultimately successful history, like braille. Such limitations in a new electronic device would lead to rejection. Fortunately, the present generation of electronic devices, while far from universally successful, already have received much higher percentages of acceptance among the blind subjects tested.

In spite of these somewhat encouraging signs of specialized uses of very limited machines at very slow speeds, the real goal is rewardingly high speed with only negligible training and at only mild psychological pressure or stress. Even so, any electronic reading system which we now envision can only supplement, not replace, the various existing systems such as sighted readers, braille, records, and tape. Each of these has both advantages and disadvantages.

Sighted volunteers are often available at certain times and places, at no economic cost but at intangible costs of delay, compromised privacy, and perhaps implications of censorship. Paid readers, though excellent, are expensive and are available only as scheduled. Braille, as we have seen, is only sparsely used, especially by the adventitiously blinded adult, in spite of its potentially adequate reading speed and its value for preparing and reading back one's own notes and manuscripts. The Talking Book (which

introduced 33 rpm records fifteen years before routine commercial use of long-playing records) is very widely used for both study and recreation, and dictating machine records or tapes have been used effectively for texts. In spite of rapid increases in numbers of books and magazines recorded in spoken form in recent years, these excellent systems are obtainable for only a very limited portion of the total inkprint available to the sighted reader. The rather recent availability of inexpensive portable tape recorders has helped to reduce the problem of personal correspondence with understanding and cooperative friends. These aids, however, do not provide for bank statements, proofreading of one's own touchtyping, or other functions normally requiring vision but scarcely recognized as literary "reading."

This distinction contrasting long-term reading of major books or magazine articles with short-term deciphering of brief but important passages, notes, or figures may not have been clearly recognized in some past efforts. This difference may be compared with the problems of fluent translation of a foreign language contrasted to slight but valuable "guessing" ability to read menus, street signs, time tables, and the like without seeking a truly competent translator. Many of the Ph. D. candidates passing their foreign language examinations have very limited reading speed indeed, yet they have attained some slight confidence in their ability to tackle a foreign reference independently—or at least to translate a title and rule out its applicability!

The more sophisticated reading systems, though, must approach the ability to translate fairly smoothly at sight, even if not the ability to read one's native language silently at the speeds now urged by courses in rapid reading. Such machines are still some years in the future. The advances in computers, machine translation, linguistics, and psychology give increasing hope for rapid reading machines. (Some even dream of artificial vision.)

Nevertheless, a serious and sustained effort on a spectrum of projects pointed specifically toward the problems of the blind seems necessary to capitalize on advances in other fields. Originally, there was general agreement that there was no likelihood that commercial character-reading machines would be directly useful for the blind because the major commercial applications were for very high reading speeds on very limited choices among "cooperative" characters, often only ten digits, in a single font and in a prescribed location on a standard single-sheet document like a check. While there has been growing experimentation on multi-font machines and on even more complex tracking mechanisms suited to bound magazines or books, the general supposition still holds.

Likewise, there seemed little probability of commercial use of machines producing spoken letters, digits, or words once the characters were known. Thus, for the special needs of the blind the studies at Metfessel Laboratories on "spelled-speech" and at Haskins Laboratories on various means of pro-

ducing spoken English words and sentences have seemed important to the VA program. While fortunately there is now some commercial interest in spoken output of computer storage, stock market quotations, telephone numbers, or the like, the present applications typically require only small vocabularies compared with our goals. Likewise, brief commercial messages may not require strict conformity with such linguistic standards as Miss Gaitenby of Haskins discusses herein, yet these rules for intonation and duration should be followed in a reading machine intended to provide to the blind comfortably speech-like output of lengthy texts.

A large fraction of the legally blind fortunately have some partial sight, so every effort should be made to assist such patients by high-power prescriptions in spectacles, by magnifiers and illuminating systems, by telescopes to read distant street signs, and especially by careful and prolonged counseling and follow-up examinations. Some partially sighted patients can travel safely without further mobility aids, yet even with the best magnifying systems they cannot read ordinary print. Such cases, as well as the totally blind, should benefit first within the next few years from slow deciphering equipment requiring extensive training and later from more elaborate electronic reading machines capable of assuming more of the burden of bringing the printed word automatically to those now deprived of independent reading.

THE SIXTH TECHNICAL CONFERENCE ON READING MACHINES FOR THE BLIND

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INTRODUCTION

On a number of occasions over the past dozen years, the Prosthetic and Sensory Aids Service of the Veterans Administration has brought together individuals with an interest from varying viewpoints, in the formidable problems involved in developing reading machines for the blind. A number of such meetings were rather informal though highly productive conversations. During the period 1954–58 five more formal technical conferences were held, each resulting in a host of new ideas and techniques. For a variety of reasons it was not feasible—nor really necessary—to organize a sixth conference until this year. It is the sincere hope of the writer that he has adequately summarized the proceedings of this meeting, which included display of several varieties of operating equipment.

Even though much of the nation was bogged down with heavy snowstorms, 61 persons attended the Sixth Technical Conference on Reading Machines for the Blind held January 27–28, 1966 at the Veterans Administration Central Office, Washington, D.C. It is estimated the attendance was down about 30 percent as a result of the storms. Tabulating the current affiliations of the participants shows that 17 were from the educational fields, 15 from industry, 14 from agencies for the blind, 13 from Federal government (Veterans Administration—7, National Institutes of Health—2, Vocational Rehabilitation Administration—1, Library of Congress—1, United States Navy—1, National Bureau of Standards—1), one from the National Academy of Sciences-National Research Council, and one a private practicing ophthalmologist. Professor Thomas A. Benham of the Department of Engineering at Haverford College, Haverford, Pennsylvania, served as chairman as he has done so many times before at earlier conferences in the series. A list of the six Veterans Administration-arranged conferences appears below:

Conference No.	Date(s)	Location	Number of participants
1.........	Aug. 20, 1954.....	Commodore Perry Hotel, Toledo, Ohio...	11
2.........	Apr. 25, 1955......	Franklin Institute, Philadelphia, Pa......	24
3.........	Aug. 3, 1955......	Rockefeller Institute, New York, N.Y......	38
4.........	Aug. 23–24, 1956..	Veterans Administration, Washington, D.C.	50
5.........	Sept. 17, 1958.....	National Academy of Sciences, Washington, D.C.	68
6.........	Jan. 27–28, 1966..	Veterans Administration, Washington, D.C.	61

Although there is a gap of over seven years between the fifth and sixth conferences, certain other meetings arranged under different auspices were held in that period and have served some of the same information-exchange purposes. Among these were the Human Factors Society Sensory Extensions Symposium, Cambridge, Massachusetts, Sept. 12, 1960; the Office of Naval Research-National Bureau of Standards Symposium on Optical Character Recognition, Washington, D.C., Jan. 15–17, 1962 (1); the International Congress on Technology and Blindness, New York, June 18–22, 1962 (2); and the Office of Naval Research-American Optical Company Symposium on Optical Processing of Information, Washington, D.C., Oct. 23–24, 1962 (3).

CONFERENCE AGENDA

The major substantive subdivisions of the agenda for the Sixth Conference were as follows:

- Single-Channel Devices
- Direct Translation Machines
- Intermediate Machines
- Recognition Machines
- Output/Display Systems
- Other Systems of Reading for the Blind
- Use of Telephone Network
- Visual Effects Through Stimulation of Remaining Parts of the Visual System

In the remainder of this paper the highlights of the meeting presentations in these areas will be covered. A more detailed record of the proceedings (4) should interest those desiring to "dig deeper."

SINGLE-CHANNEL DEVICES

Mr. Leo M. Levens, chief engineer of the Engineering and Manufacturing Division, American Foundation for the Blind, New York, discussed the current status and recent history of optical probes with audible outputs. He commenced his presentation by quoting a remark made by Mr. A. Wexler (5) of Melbourne, Australia, a teacher of science to blind students: "By means of photoelectric cells coupled electrically to sound emitting apparatus or to vibrators, a great variety of phenomena normally observed by sight can be made perceptually accessible to the blind, or if need be, to the deaf-blind." Mr. Levens indicated that there is nothing new about the obviously logical combination of a set of elements to transduce information from the optical world of vision to the sound modality so useful to blind people. Dr. Edward J. Waterhouse, now director of Perkins School for the Blind, Watertown, Massachusetts, as early as 1938 used a photoelectric cell and buzzer arrangement in an apparatus used by blind students in determining the altitude of the sun.

Associated with the *input* end of an optical probe one usually finds, singly or in various combinations, lenses; light-conducting rods, tubes or fibers; illuminators; color or polarizing filters; light choppers; orifices; or irises. Light *sensors* in use include light-sensitive resistors, diodes, transistors, and photovoltaic cells. The electrical *detection* or conversion to sound is often accomplished with variable frequency oscillators or tone generators, with multivibrators, or with amplitude controlled oscillators. The power supply is usually a battery, but some permanent equipment installations may use the powerlines. The output end may involve an earpiece, a loudspeaker, or a "Sonalert" oscillator and sound-reproducing means. It should be noted that optical probes may be hand-held, or may be attached to a fixed mount, sensing materials passing by, or may be on scanning mountings designed to allow traversing any particular track.

Optical probes may be used by blind typists to orient letterheads and deal with margins. Switchboard operators use them to locate lighted lamps. Colors can be matched through use of filters. Urinalysis is possible and is important to blind diabetics. Various laboratory scientific experiments can be done by blind persons if aided with an optical probe. The blind radio repair technician also finds uses for a probe as does the blind person interested in using a telescope for astronomy.

Mr. Levens alluded briefly to the early work of Dr. C. M. Witcher (6) at AFB and MIT, which culminated in the production for AFB in 1957 of 45 "Audivis" probes (Fig. 1), by Dunn Engineering Associates, Cambridge, Massachusetts, at a reported cost of $35 each. He also referred to the devices of Messrs. A. Wexler (5), R. S. Muratov (7), and S. L. Bellinger and Dr. I. Browning (8).

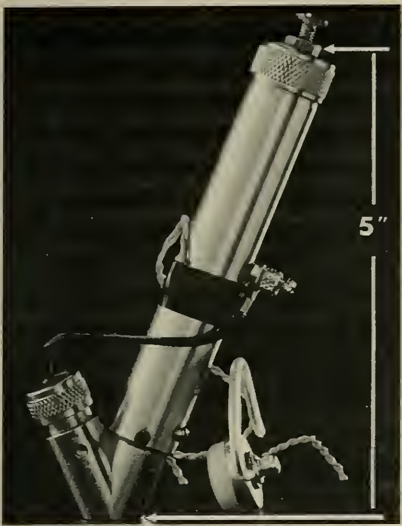

FIGURE 1. "Audivis" optical probe for the blind produces an audible output in the earpiece dependent on the amount of light incident on the input photocell.

Mr. Levens demonstrated several optical probes including one fitted to a hand-held boy scout's compass. Professor Benham, the chairman, also showed a 3 by 3 by ½ in. optical probe built by "Science for the Blind." Professor Mann mentioned related MIT students' theses (9, 10), but indicated these developments had never been carried through a thorough user-trial phase.

In addition to the optical probe devices with tactile output mentioned by Professor Mann, the writer of this paper briefly described suggestions in this area attributed to Drs. Heinz E. Kallmann and Robert J. Moon. The Kallmann idea involved a photoelectrically controlled tactile stimulator at the end of a vibrating reed, this reed itself mounted orthogonally on a second vibrating reed. As the unit passed over black on a page the two reeds would be driven electrically to vibrate, causing the stimulator tip to describe a small rectangle. Sensed with the fingertip this vibration would be the indication of black on the page below.

The Moon idea comprised a photosensitive element carried at the fingertip by a glove or cuff arrangement, and a tactile "pincher" or stimulator on the same fingertip. The power and electronics could be on the hand or elsewhere, connected by fine wires. If the finger, so equipped, were scanned over a page, a tactile signal would be received at the scanning finger whenever it passed over black.

Professor Benham mentioned a probe he had built with electrical stimulation as output. He demonstrated this and then passed it among those present for personal trials.

DIRECT TRANSLATION MACHINES

Miss Mary Jameson of London, England, a pioneer having 48 years of experience with the optophone, spoke to the group via a tape recording on "The Optophone: Its Beginning and Development." Her remarks are included in this issue of the Bulletin as a separate paper immediately following this article.

The writer, a Veterans Administration staff electronics engineer, related experiences using the Battelle 200-hour optophone training course with a blind social worker who has volunteered to take the lessons in spare moments. Despite the severe pedagogical shortcomings of such an informal arrangement, the subject has reached the 80th lesson with performance about the same as the average at Battelle Memorial Institute during their more intensive controlled learning study.

Dr. Leo H. Riley, director of the American Center for Research in Blindness and Rehabilitation (ACRIBAR), Newton, Massachusetts, told of optophone evaluation work conducted at his activity. ACRIBAR chose volunteer subjects of above average intelligence who expressed a desire to read ink-print. They were examined for physical fitness, IQ, hearing loss, psychological adjustment, and with the Battelle subject-selection test and the Seashore discrimination tests. Six persons were selected, three men and three women, with ages from 29 to 49 years, and IQ in the 110 to 141 range. The first formal lessons commenced in January 1965. Attrition in the slate of six subjects because of obtaining employment in conflict with lesson times, moving out of town, and extended illness, brought the tests to a halt. One subject reached a 7.1 wpm reading rate after 85 lessons, another 4.5 wpm after 66 lessons. The project operations are currently being revised to allow for training in the evenings and on week ends.

A staff braille instructor from the Veterans Administration Hospital at Hines, Illinois, Mr. Harvey Lauer, presented a talk on "The Potential Uses of the Optophone." Mr. Lauer's talk also appears in full following this paper. In addition, Mr. Lauer gave a demonstration of reading with both the Battelle optophone (Fig. 2) and the Mauch Laboratories "Visotoner."

Messrs. Hans A. Mauch and Glendon C. Smith were present to discuss the Mauch Laboratories "Visotoner," a miniaturized version of an optophone-style reading machine for the blind (11). The "hardware" aspects of the "Visotoner" were first considered in April 1964, and the first prototype was completed about six months later. The nine tones are the same as those used in the optophone developed at Battelle Memorial Institute. Letters within a 5:1 size range are accommodated by an automatic focus mechanism controlled by a braille-dot-marked clock-position adjustment knob. Maximum type height is 0.440 in. The unit is held by the hand and runs on long rollers coated with a high surface friction material. Once

FIGURE 2. Using the VA-Battelle optophone reading aid for the blind. Photocells in the probe which is in the user's right hand convert images of the print on the page to electrical signals which control tones fed through the earpiece. The probe is being guided along the line of print with the aid of a manual tracking device.

on a line these parallel rollers help keep the probe in the correct reading position. Hum-free operation is assured by use of power from a rechargeable nickel-cadmium battery weighing 12 oz. The "Visotoner" and hearing-aid-type earphone weigh only 10 oz. This includes circuitry comprising 38 silicon transistors, 63 resistors, 18 capacitors, and 12 diodes. Mr. Smith voiced the hope that the small size and light weight would contribute much towards the unit's acceptance by blind users.

Mr. Loyal E. Apple, chief of the Central Section for Rehabilitation of Visually Impaired and Blinded Veterans, Veterans Administration Hospital, Hines, Illinois, addressed the group on "Factors Affecting Reading Machine Instruction in Rehabilitation Centers." His complete paper is given following this article.

In the general discussion which followed the presentations relating to optophones, Dr. Selfridge inquired about the evidential basis for the use of tones as the optophone's display. Professor Mann queried the choice of the particular tones used, and the fact that the same ones are so often used. Reference was made to the late World War II Committee on Sensory

Devices work wherein tones emerged as a reasonable output, and to the brief exploratory work at Battelle. Drs. Cooper and Murphy and Messrs. Mauch and Freiberger tried to answer the questions in part. The author said he felt a definitive study as to the best audible output for a direct translation machine was yet to be made. Dr. White entered a plea that tests on such outputs could be done through simulation without building actual devices. He also reiterated a point he made several years before, that reading speed in words per minute is not a good measure of performance with a reading machine. He feels a measure of the time taken to read a telephone number in a telephone book, or to get information from a label, would be a much more appropriate rating means.

Dr. Murphy spoke briefly of the need to make graphic materials like charts and maps available to the blind. Sighted persons often make raised line drawings for the blind, but the Naumburg Visagraph and the later "Faximile" Visagraph were attempts to mechanize this process. These devices optically scanned the ink-print original which was mounted on a rotating drum, and with a solenoid-operated embossing point produced embossed replicas in tin or aluminum foil. Professor Mann mentioned a Gestetner process for making a stencil from an ordinary ink-print original, using a special ink in the Gestetner stencil duplicating process, then briefly baking this ink to produce a hard, raised, tangible image. Professor Benham added the point that with automatic embossed copymaking, the editing function of a human embosser is lost, i.e., confusing non-essentials are embossed along with the necessary material of the drawing.

Professor Geldard reviewed his work on the "Optotact" [a] idea at Princeton University. After mentioning the lack of success of just presenting signals, in whatever form they happened to be, to the skin, he emphasized the importance of determining just what kinds of discriminations the skin can best make. Passing quickly over discrimination in the intensity and frequency dimensions, he said the skin is superb as a temporal discriminator. Space or locus discrimination is most difficult for the skin, and many proposed information transfer means employing the skin are conceptually at great odds with what is known of communications via the skin. Professor Geldard is using a ten-channel system with ten small vibrators mounted on the body away from the head and shoulders and rib cage to prevent cochlear assist. Two vibrators are mounted on each arm, but not in symmetric positions, two on the abdomen, and two asymmetrically on each leg. Signals of 200 milliseconds duration and 2-second spacing were used in paired discrimination tests. The "signals" were derived through use of an IBM typewriter to type symbols, then scanning at controlled speed past a Battelle optophone probe whose outputs were amplified to control the body-mounted vibrators. As with the optophone, a thin long vertical bar would excite all circuits, and

[a] Now called "Optohapt."

all vibrators would operate. With a horizontal line only one vibrator ideally would operate. Other shapes, including letters, would give spatial-temporal patterns of vibrator activity. Ranking the patterns used in decreasing order of discriminability Professor Geldard found the period, quotes, a solid black square, hyphen, equal-sign, arrow to right, plus sign, letter "I," square shape in outline, Greek letter π, slash, diamond shape in outline, and letter "L." Note that the easiest letter, the "I," is in ninth place, the next, the "L," in 15th, and "A" is in 40th. Direct translation of letter shape for skin sensing by these means does not seem a fruitful procedure. Professor Geldard said one of the main lessons learned here is that the skin does not like Euclid.

Professor Linvill spoke briefly of his work (12) on tactile devices in collaboration with Dr. Bliss at Stanford Research Institute. An old idea enhanced with new technology is how he assesses the reading device using a 96-point 12 by 8 array of piezoelectric bimorph stimulators. Letter information, computer simulated so far, is used to produce a "Times Square" presentation of tangible letter shapes moving across the perforated plate supporting the sensing finger(s). Piezoelectric reeds are simple and efficient "motors" for the purpose. A vibration of only one micron amplitude can be felt, and one of 10 microns is easily sensed. With a stylized type font based on an 8 by 5 matrix, all three subjects could read at 20 wpm after 10 hours of training. Changing type style slowed "readers," but in time they learned the new style and were able to read a variety of fonts. Even though harder to read by eye, showing only ⅗ of a letter at a time did not seem to slow tactile reading. Showing lesser fractions did interfere with performance. An enormous amount of improvement is realizable through training, and Professor Linvill is convinced 35 wpm is achievable with this system. Making use of silicon monolithic circuits fabricated in Stanford laboratories, he hopes to construct a small unit capable of reading from ordinary print.

The reading machine of central importance in the Veterans Administration program at Mauch Laboratories (11) is a medium cost, personal, recognition-type device. To locate lines of type for this machine, and to resolve printed symbols beyond its capabilities, a set of raised pin stimulators giving somewhat the impression of tangible embossing was incorporated as part of the input probe. Considering this device as possibly useful by itself, it was constructed as the "Visotactor B" without the photocells used in the recognition machine. The "Visotactor B" (Fig. 3), portable reading machine for the blind developed at Mauch Laboratories, was described by Mr. Smith. Eight vibrators, in four pairs, are used two to each of four fingers which are inserted into four finger-rests of the unit. A blind subject has been trained at Mauch Laboratories on the "Vistotactor B," using the Battelle 200-hour course. At the time of this writing, the subject was reading from an adult's book of mystery stories, for 20 minute test periods, averaging about seven wpm. Four more "Visotactors" are to be constructed in the near future.

FIGURE 3. The "Visotactor" reading machine for the blind. Vibrating stimulators feed tactile information to the four finger-tips according to the printed letter shapes on the page over which the device is rolled.

INTERMEDIATE MACHINES

Dr. Nye, who had worked at Britain's National Physical Laboratory but who is currently at California Institute of Technology, recalled some of the work done at NPL (13) with so-called intermediate machines. These reading machines are "intermediate" on a scale having direct translation devices at one end and recognition machines at the other. Some measure of recognition and information processing takes place in these machines above and beyond the rudimentary operations of a direct translator, but short of the rather complex operations in a true recognition machine. The aim is to combine as well as possible the simplicity and low cost of the direct translation type with the improved performance of a recognition type.

In one set of experiments at NPL, a lower case alphabet was scanned by successive vertical scans and the following six letter-features were determined for each letter:

ascender
descender
ribbon height vertical
upward curving line
downward curving line
horizontal line

This feature information was stored in a token matrix, and after a smoothing conversion to an analog form, the information was used to control production of an audible output. One of a number of possible arrangements involved control of six parameters in an "artificial larynx" (hiss generator, three formants, larynx frequency, larynx amplitude) by the processed information from the letter shapes scanned.

Comparative tests of several NPL developed outputs led to a general conclusion that the richer the audible display the better in terms of probable reading speed and comprehension. Dr. Nye indicated that while natural speech is an ideal output form for a reading machine, we need not wait until mechanized speech production is perfect and fully understood. Out-

puts embodying known psychoacoustic data relating to displays may well be studied now to produce non-speechlike outputs superior to the optophone types now being tried.

RECOGNITION MACHINES

Messrs. H. A. Mauch and G. C. Smith gave some details of the work on a recognition machine at Mauch Laboratories, Inc., Dayton, Ohio (11, 15). Mr. Mauch made clear the differences between his inexpensive, fairly slow, and relatively portable device for use by the blind, and the large, expensive, high-speed devices used in industry. Because the blind user shares much of the burden of its operation, the machine for the blind can be commensurately simpler than its fully automatic counterpart used in industry. The blind user may have to find the text on the page, align the page in the device, change lines when the end of a line is reached, track along the line, and make size-of-type adjustments.

The Mauch unit is designed to recognize upper- and lower-case letters and ligatures in about nine common fonts. A tactile output is also provided, when necessary, by the "Visotactor A," the optical probe part of the system. Numerals and graphic indicia which the device fails to recognize may be "read" tactually by operating in the Visotactor mode, at slower speed.

Mr. Smith cautioned that only a laboratory prototype of the recognition reading machine has been tested to date. This device does, however, recognize typed or printed letters, and then produces an audible output in wordlike groups of the spelled-speech sounds developed at Metfessel Laboratories. With the aid of a series of slides Mr. Smith briefed the audience on the technical aspects of the recognition reading machine. He referred to the "multiple snapshot" principle and the electro-optical directional effect realized in the slabs of polycrystalline photoconductive material (15) depending on the current source and sink edges versus neutral edges. The photocell development and fabrication work of the Laboratories was also summarized. Trials of the completed device show it can accommodate for some misalignment of printed material relative to the scanner, but plans are already made for an improved version which will be more tolerant of misalignments.

In planning the conference it was hoped that representatives of the character-recognition industry would indicate how their work and achievements could be used to enhance the reading machine program for the blind. Apparently unable to attend because of the severe weather, most expected representatives of industry could not be heard. Mr. David H. Shepard, president of Cognitronics Corporation and a pioneer in character recognition work (16), provided a summary. He mentioned equipments of Philco Corporation, Recognition Equipment Company, Intelligent Machines Research (now Farrington Electronics, Inc.), IBM, Burroughs, NCR, RCA,

and Control Data Corporation (Rabinow Division). Mr. Shepard feels problems of format, pictorial material, advertisement layout, overlapping typed characters, and imperfections in paper and printing may pose the greatest difficulties in automatic reading for the blind.

OUTPUT/DISPLAY SYSTEMS

Professor Milton Metfessel plans to complete a final report on his project in mid-1966 which will contain detailed information concerning the generation of spelled-speech alphabets. It should be noted that spelled-speech is an audible output or communication system based on pronunciation of the series of letters comprising a text. The distinguishing aspect of the Metfessel system is that the pronunciation for each letter is carefully tailored so that one stored version may be used in any context while maintaining a high level of comprehension and coalescence of the letters into smooth-flowing word-like groupings.

Because of the expected thorough report, Professor Metfessel avoided great detail in his talk. Use of the system presupposes a knowledge of spelling. The communication rate for spelled-speech is very flexible, ranging from 1 wpm to 120 wpm. At slow rates, up to about 15 wpm, most people understand almost any kind of spelled-speech with little or no training. Problems really begin at speeds of about 70 wpm. Professor Metfessel feels he has solved the problem in that he is able to put together any text from his set of reference letter-pronunciations with a fairly smooth spelled-speech output at speeds up to 120 wpm.

At this meeting, several samples of spelled-speech were presented as well as recordings illustrating how the letter pronunciations are achieved. Compatible spelled-speech involves use of the same voice recording on the same tape at the same sitting with all adjustments held constant. The recording speaker speaks a sentence which ends with a group of letters to be pronounced. From these the desired letter is singled out to become one of the reference set.

Lack of a good standard means for measuring word-per-minute rates was mentioned along with some technical details of spelled-speech production. Professor Metfessel mentioned equal interval presentation, the "framing" of the letter sound in the interval, cutting out terminal and/or initial parts of letter sounds, use of rhyme in alphabet production, and the span of attention capabilities of a person receiving spelled-speech.

Dr. Franklin S. Cooper and Miss Jane Gaitenby of Haskins Laboratories, New York, reported on their work on audible outputs for reading machines for the blind. Aiming at a high performance unit, they have assumed that the machine has to "talk English." Hoping to use the results of the many others working on optical character recognition, the Veterans Administra-

tion has retained Haskins Laboratories to study the complementary or output part of the reading machine. Two principal approaches have been followed, one involving outright synthesis of speech, the phoneme being the unit element of consideration, and the second involving compiled speech, the word being the unit. Both avenues have been pursued to a point where outputs have been demonstrated. During the course of these studies, important advances in both equipment technology and understanding of machine production of speech have occurred. On the basis of this new knowledge (17) a most promising form of speech output for a reading machine has been proposed. Dr. Cooper calls this "re-formed speech." One possibility for its production involves a speaker first recording a vocabulary of words, perhaps 7000 or so as was done for compiled speech. These words are then stored in digital form in digital stores which are becoming more commonplace as digital computer technology advances. To use the words in an output system one must take them from the store in accordance with the letter and word knowledge from the character recognizer. The novel possibility here is that instead of coming up with a single output pronunciation as with compiled speech, the digitized word information can be further processed through a "digital spectrum manipulator." This extra step allows for variation of pitch and amplitude contours of the words. Such variational control, based on contextual data, should provide for a more natural and hence more acceptable speech-like output of a reading machine.

Miss Gaitenby played some recordings of compiled speech run at about 98 wpm drawing on a 7100-word recorded vocabulary. Selections where all words were available were demonstrated, and others requiring spell-out of the words not in the vocabulary were played. Miss Gaitenby touched on her extensive studies aimed at the selection of the most appropriate pronunciations of the words to be entered into compiled speech vocabularies, and also her experiences with spelling of words not in the system. These spelled words are often the unusual words, or proper names, and are generally *not* easy to comprehend if spelled at a fair rate in admixture with the pronounced words. Trials are yet to be made of spelled words in context using Metfessel's spelled-speech rather than just citation spelling-bee pronunciations.

Dr. Cooper summarized by mentioning the several types of reading machine output systems he has considered. He cited synthetic speech, compiled speech, and phrase-reading devices of several kinds and complexity levels. Some economic forecasts were made. He pointed out that some systems will probably be more expensive than a human reader; however, a word reading machine with some intonation could possibly compete economically. He felt that in the not too distant future, information dissemination problems for blind people will be largely in the administrative and organizational areas rather than in the technical.

The "Speechmaker" automatic speech generation equipment developed at Cognitronics Corporation (18) was described by the company's president, Mr. David H. Shepard. The heart of this device is a 3-in. photographic film audio memory drum with up to 32 tracks, one track for each of 31 utterances, words, or phrases, and one for a timing pulse. A light source and aperture provide a narrow light beam that is directed through the rotating drum. This light beam is modulated by the prerecorded audio signal on each track, and is in turn detected by silicon photosensitive cells located behind each track within the drum. The output of the photocells is then amplified to a level compatible with the particular employment of the unit. Switching for selection of the sounds to be heard can be done on a basis of either 31 individual switch closures, or by a binary decoding matrix performing the selection function from a standard 5-bit binary code. Mr. Shepard mentioned that the capacity of these units can be increased beyond the 31 tracks mentioned above, and that the prices vary from under one thousand to several thousands of dollars. The Cognitronics work has been chiefly device oriented in contradistinction to work at the Metfessel and Haskins Laboratories where the utterance has been studied. Mr. Shepard suggested that a merging of these approaches through sharing specialized knowledge could be very fruitful.

OTHER SYSTEMS OF "READING" FOR THE BLIND

The managing director of the MIT Sensory Aids Evaluation and Development Center (SAE&DC) (14), Mr. J. K. Dupress, spoke about some modern trends in braille translation and production. A computer is generally considered the appropriate means whereby material in one form or another can be encoded into braille. A key punch operator not knowing braille, or a perforated tape such as "Teletypesetter" or "Monotype" can be employed to feed text to the computer. The IBM 709 used at the American Printing House for the Blind has been employed in this translation service and has transcribed over 100 books to Grade II Braille so far. Several persons have written programs for braille translation using smaller computers, but the output from these has never been perfect Grade II Braille.

Several student theses at MIT have involved braille and the mechanized production of braille (19, 20, 21, 22, 23, 24). Staff members at SAE&DC are working to carry some of these student efforts closer to completion.

Mr. Dupress also referred to means for the production of small numbers of copies of braille documents, to mechanical braille displays such as the IBM belt reader and the Blanco device, and to recent attempts at small powered-braillers. He also touched on the recent special application work with high speed line printers of the kinds used in the computer industry. With braille-cell-embossing type bars and properly resilient backing platens, these printers have produced good braille at high speeds.

Mr. Dupress concluded with the thought that computers owned or operated by school systems may very well be used to generate braille in the future.

Mr. Alfred Korb, from the Division for the Blind of the Library of Congress, spoke about Talking Book, rapid speech, and recent efforts to increase speed of recorded speech without altering the pitch. He mentioned that some fast speaking radio personalities talk at 200 wpm, American Printing House for the Blind and American Foundation for the Blind usually record at 150–175 wpm, and that some recordings are at 80–120 wpm. By way of contrast he estimated a sighted twelfth grade student reads silently at about 250 wpm and a good braille reader at 90 wpm. The Library of Congress is looking for applications of compressed materials by selected surveying of some of the 80,000 people registered in the Library of Congress program. To date, some have complained of difficulty in understanding the speeded speech.

Mr. Alan Beaumont of the Solocast Company, Stamford, Connecticut, briefly described and demonstrated the Solocaster, a high fidelity, portable, record player. The unit is battery powered, light in weight, transistorized, and can be played in any position, even swinging through the air, thus offering "in-motion" performance.

USE OF TELEPHONE NETWORK

Another class of alternative solutions to some of the reading problems of the blind, mentioned at these meetings since the Second Conference held in April 1955, generally involves use of the telephone lines to transmit a facsimile of a printed page from the blind user's location to a central office. The graphic matter is sensed or read by machine or operators at the central location, and the information is then conveyed back over the phone to the user. Messrs. David H. Shepard and Joseph H. Kroeger of Cognitronics Corporation demonstrated publicly for the first time two variants of such a system. In the first, typed numeric data were scanned on a rotating drum facsimile-type apparatus at the Conference in Washington. The video information from this scanning was sent by the telephone lines to the plant at Briarcliff Manor, N.Y., where automatic character recognition was accomplished. The numerals were then "spoken" back over the telephone in human-voice recorded numerals by the "Speechmaker," the automatic speech-generation machine developed at Cognitronics and referred to above. In the second, alpha-numeric material scanned in Washington was read back over the telephone by a sighted reader from a CRT display at Briarcliff Manor.

The scanning system used in the Cognitronics demonstrations had an adaptive feature in that the pickup head traversed blank areas of the paper at a higher rate than it did for print-bearing portions. Scanning efficiency

was thus increased. Pulse code modulation and integrated circuitry contributed to the success of the operation. Initial prices of these scanners are expected to range between $2500 and $7000 depending on the model. Telephone charges and costs of the central office operation will also be involved. There was a brief discussion of the economics of such a service, but in the time available and with the data on hand a clear resolution of the economic aspects was not possible.

VISUAL EFFECTS THROUGH STIMULATION OF REMAINING PARTS OF THE VISUAL SYSTEM

The use of ophthalmic spectacles is commonplace in the solution of the reading problem of many persons. Conceptually it is but a short step to consideration of prostheses analogous to eyeglasses for use when the visual dysfunction is other than just a refractive error. While simple enough in concept, in practice direct replacement for defective or missing parts of the visual system has, to date, proved most difficult. The subject has received attention for a long time as one may learn if the 25-item reference list on page 549 of the book *Blindness* (25) is noted along with the seven newer citations on pages 588–589 of the reprint edition of the same book.

Professor Theodor D. Sterling, chairman of the Committee on Professional Activities of the Blind, Association for Computing Machinery, spoke briefly on the subject of "artificial vision." He pointed out the naturalness of the thought process which, on recognizing a biologically defective element causing the blindness, then quickly proceeds to the areas of direct visual prosthesis and stimulation of the visual centers as a replacement for the lost sense. As technology gallops forward more serious researchers are beginning to explore the practical possibilities of such visual prostheses. Because of the great human values involved in blindness and proposals for its amelioration, discussions of artificial vision have been generally quite tactfully conducted within the scientific community. Currently, physiologists and psychologists are grappling with problems of how to preprocess optical information from the environment so as to recode it to appropriate electrical signals which may eventually find their way to the brain. Additional evidence of the current interest in visual prostheses traceable to recent technological advances may be found in Dean George A. Mallinson's paper (26).

ADJOURNMENT

Prior to adjournment the group considered project areas for continuing or future work. Included were comments on time compression and expansion of speech, graphics and images via telephone lines, time sharing of centralized expensive equipments with telephone terminals in the users' homes, improved means to prepare embossed drawings, instructors and

instructional techniques for optophone, Visotoner, and Visotactor. The chairman thanked the participants and the Veterans Administration and then closed the sessions.

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THE OPTOPHONE: ITS BEGINNING AND DEVELOPMENT [a]

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This is Mary Jameson speaking from London about the optophone, its beginning and its development.

I first met with the optophone in 1917 when I was 18 years old I learned what was then the optophone code on an instrument built in the inventor's laboratory. This optophone had one selenium cell which received light reflected from the printed page being read. White paper emitted a full musical chord; the reading was done by the tones blotted out by the black print as the scanner passed along the line.

In a word, reading was effected by what one didn't hear. This was not easy and the frail construction of the instrument added to one's difficulties. The focusing arrangements would slip out of place if anyone walked heavily across the room. However, by August 1918, I could manage a speed of about a word a minute, sufficient to show that print reading was possible. Then, a most fortunate event occurred. Admiral Sir Reginald Deighton attended a demonstration given by me at King's College, London, and he introduced the optophone to Messrs. Barr and Stroud of Glasgow, who agreed to manufacture it. The optophone, when manufactured, showed a threefold advance: It was no longer frail to handle; the scanner was equipped with an excellent driving mechanism; and a second selenium cell, a balancer, had been added so that the printed letter signals came from the black print and not from the white paper.

The British optophone still uses the Barr and Stroud driving mechanism. It provides a rhythmic flow of signals which can be varied in speed by turning a screw. At the same time it can be held up by hand pressure if one needs to study a signal in detail. If only the selenium cells had been suited to their purpose as this drive was, the optophone would have been of immediate practical use.

The volume of sound given by these cells was uncomfortably low and they were apt to crackle after an hour or two of use. Yet the work on the balancer cell principle was not wasted, but was applied by St. Dunstan's

[a] Transcribed from a taped recording presented at The Sixth Technical Conference on Reading Machines for the Blind. Several references to recorded sounds have been deleted from the text. A review of the conference precedes this paper.

when, twenty years later, in 1944, they took up the optophone and substituted two photo-electric for the two selenium cells.

The new cells gave really adequate volume of sound and after microphonic and focusing difficulties had been overcome, provided a useful instrument. Later, in the 1950's, Mr. W. K. Hill became interested in the optophone. His work on the focusing arrangements has markedly improved the definition of the output and made it easier to distinguish between shapes as similar as lower case "b" and "h" and "i" and "e."

There remained, and still remains, a serious drawback to the British optophone output; the signals are not heard against a silent background as they are in the case of the Battelle.

Having reached the 1960's, may I sum up the position as I see it. I think a driving mechanism with the attributes of the British system makes for ease and speed of reading. This should also be said for a silent background to the signals.

It is possible that further study will show that the British optophone gives better definition than the Battelle in the presentation of its signals.

Regarding tracking, one of the accompanying photographs (Fig. 1) taken by Mr. Hill shows the Battelle probe fitted into the British scanner so that it can be operated with the British drive. This allows a rhythmic flow along the printed line maintained at a speed desired by the reader. A turn of a screw increases or decreases this speed. Normally, I run the scanner a little faster than I can pick up every detail of each signal relying on hand pressure to slow up my reading if necessary.

Regarding definition, or the clear cut presentation of the signals, I find the British optophone somewhat superior in this respect to the Battelle, in spite of background noise.

Mr. Hill thinks the image reaching the print from the British optophone scanner is slightly narrower horizontally than that from the Battelle, and this has to do with the sharper output from the British optophone.

Coming now to the teaching of optophone reading, I prefer the letter-word to the word-letter approach, the correspondence between the shapes and sounds of the signals is such a powerful aid to the memory besides

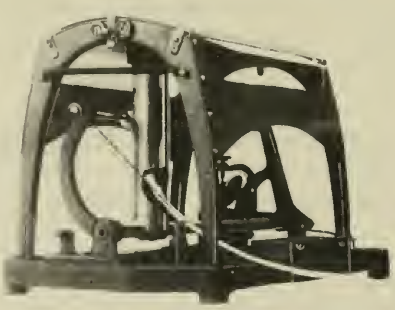

FIGURE 1

stimulating immediate interest. For example, having told the student that every vertical line produces a chord, he quickly grasps that lower case "m" having three vertical strokes has three chords; he will realize for himself that "n" must have two.

I have said I prefer the letter-word method, and that is true basically, but I would rather call it the "letter and word" method because I would gradually introduce words as the student progressed with the letters. I would start with two letter words, building up to words of about five letters. In this way I would construct a bridge between separate letters and instruction material such as the Battelle "word" method.

Also, with modern amplifying equipment I would not think instruction on tape recordings necessary, but would take the output direct from the optophone.

This system would permit varying reading material and speed of presentation according to the speed of the students and the interests of the experimentor.

In the past I have had to move from an alphabet sheet of separate letters to a child's primer having words of four, five, and even six letters, and I think the jump is too great.

I know that the word-letter method is used satisfactorily for teaching students to read with their eyes, but doesn't the situation differ from that of aural readers? The eye can take in at a glance a considerably greater range of characters than the ear, in fact the ear receives them one by one.

Being able to run the drive at a speed greater than that at which every detail can be picked up does help to speed the reading, however. Concerning the use of context, I cannot feel that this should be deliberately taught. It is often far easier to read the text than to guess at or think out what is likely to be ahead. Also, it seems to me that nothing should deflect us readers from performing what is still the basic task of helping the experts to discover the clearest possible code and the best manner of presenting it. Nevertheless, in practice one becomes familiar with the style and vocabulary being met with in the work being read and one can move quickly past names and other words which have become familiar.

I had hoped to include a sample demonstration of the Battelle output using the British scale, but it does not seem to suit the Battelle optophone, the frequencies needed for wavy letters such as "v" and "w" seem to be too close. Where these letters narrow to a point, a merging and roughening of the tones is caused. Mr. Hill has cured the trouble by spacing out the six tones.

Although this situation does not allow me to attempt a fair comparison between the Battelle and the British scales, I thought it might be useful to try comparing a six-tone with a nine-tone scale. For this, I recorded the words "winter" and "snow" from your instruction tape recording No. 15, then I recorded the same words direct from the Battelle I have here. As so

often happens in this kind of work, I met with a snag; the general quality of the instruction tape recording is much clearer than from the Battelle used by me.

In this short survey I have tried to do three things: To indicate the value of the British-type drive, to illustrate the advantage of the Battelle quiet background, and to suggest the direction which it seems to me that further research should take with the object of improving the clarity of the output, vertically speaking the best number and choice of tones, horizontally speaking for the clearest possible definition.

When I have recovered from the operation for which I enter the hospital on January 12, I hope to resume my studies. In the meantime, may I wish this Conference the success its importance deserves.

FACTORS AFFECTING READING MACHINE INSTRUCTION IN REHABILITATION CENTERS [a]

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Hines, Illinois

After watching the progress of Battelle Institute and Mauch Laboratories, my superior, Dr. W. T. Liberson, Chief of Physical Medicine and Rehabilitation Service at Veterans Administration Hospital, Hines, Illinois, and I were pleased when it became possible for us to have one of the Battelle machines at Hines. Dr. Liberson's own interest in the application of electronic technology to the amelioration of physical disability was a factor in making this venture possible.

On May 13–17, 1963, Mrs. Genevieve N. Miller, Assistant Chief of the Central Rehabilitation Section for Visually Impaired and Blinded Veterans, went to Battelle Institute in Columbus, Ohio, for training which would fit her to instruct in the use of the machine. Mrs. Miller began the training of Harvey Lauer, Braille Therapist, in April 1964. They proceeded through the two hundred lessons of the Battelle series as their working time would allow, until Mr. Lauer completed his instruction in December 1964. In addition, Mr. Lauer put much of his own time and energy into the program and is to be highly commended. Mr. Lauer is here to present his own experiences to the group, and I will comment no further.

The reading machine is not a substitute for braille reading and writing. The reading machine is an additional communication tool and offers great freedom in perceiving the ideas contained in the printed or typed word. Braille gives much greater flexibility in retrieving ideas that have been set down for the writer's use.

There are four ways in which a blind person can obtain information from the printed word—braille, recordings, a sighted reader, or the optophone. All except the optophone require the action of a second party. The optophone, however, will not be able to completely displace any one of the three, for each has its invaluable aspects for the blind person.

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[a] This paper was presented at The Sixth Technical Conference on Reading Machines for the Blind sponsored by the Veterans Administration, PSAS, Washington, D.C., January 27–28, 1966. A review of the Conference appears elsewhere in this issue.

There are factors which govern the adoption of new programs in the comprehensive rehabilitation program of the center at Hines. These apply also to reading machines. There are the factors of validity and relevance which must be considered first. After these come the factors which govern inclusion.

When a new program involves any device, it becomes important that the device has technical validity, and does what it is designed to do, reliably. Portability, size, repairability, and other factors important to engineers come into play and seem to be adequately met by the Battelle device.

There is a validity of instruction which is not as clear as I shall define it. Instructional validity has to do with human beings being able to learn to use the device with a reasonable amount of time and effort. The instruction series for the optophone seems to have been well validated. On the basis of the experience with Mr. Lauer, we would hypothesize that the actual time the instructor spends with the student might be reduced without serious harm to learning efficiency.

Relevance of both device and instructional program to the management of sight loss is important. The deepest motivation springs from participation in activities which promise the most success in managing the greatest areas of life affected by loss of sight. This is the way in which we would define relevancy. The device and the techniques, which are to be learned for its use, are always weighed in this manner. Indications are that the optophone has relevancy for some blind persons but is not universal in its applicability in solving the problems of blindness.

The factors governing inclusion of a device which has validity and relevance into an established program of proven worth are very complex. Inclusion may be made by displacement of a previously established program element, or by addition to the established schedule of the program. In order to displace a program element, the program to be included must answer the same difficulties of blindness in a better way than the element being displaced. That is, a mobility program can displace a mobility program or a counseling program can displace a counseling program if they have a higher relevancy. The optophone is an additional area of function and does not duplicate any of the established types of program and, therefore, could not displace them.

New programs can be included by addition to the established programs when there is a high level of relevancy and if the new program is for an area of function not touched by existing programs. Such additions do have an effect on participants as well as other phases of the program. The time, energy, and attention of participants can only be spread so far before some part of the program in which they are participating begins to be slighted. Motivating blind persons to expend energy at a high level is a part of the staff function in this center, but there are reasonable limits.

Although there are negative factors, inclusion of the optophone program into the center should be by addition, rather than displacement.

If there were a very limited number of individuals with whom we would deal, an optophone program could be worked out with only a limited increase of the patients' stay in the section. This would have to be done by adding evening and weekend classes on the optophone and by some modification of the training regimen developed by Battelle Institute.

I do know of a center where substitution or displacement of a sort is a part of their programing, which might include the optophone program by displacement. Perhaps both should be tried.

The kinds of knowledge and skill which are found in a blind rehabilitation center would provide an apparently promising environment in which student, instructor, and machine might be gotten together. A center might set up a specialized program for men who wished to be admitted specifically for training with the optophone, in much the same way that dog guide schools admit for only one area of study. Such an insulary program, if significantly extended, would need additional space, equipment, and staff; but, it would more nearly meet the instruction time criteria developed by Battelle Institute. These criteria are much longer than the time span usually occupied by the rehabilitation process.

Instruction on the machine might also be tried on a home visit basis, wherein the teacher instructs the prospective user in his home. The machine would stay in the home and the student might use it for practice at his convenience.

There is a factor which seems implicit in the development of the optophone. That is, that machines will be issued to blinded veterans who are satisfactorily trained in their use. This is a strong motivational factor. Blind persons who learn to use the machines must have some assurance that the optophone will be available to them after they have satisfactorily completed their training. It is hoped that blinded persons may seek out a skill with the optophone as a matter of intelligent self-interest, wherein after they learn to use the machine it will be available to them.

There are other human factors which are not clearly understood yet. These seem to be principally those of readiness. We will not understand these until we have spent some time earnestly training blind persons to use the optophone. Not all blind persons have a strong sense of urgency about learning to read a new way, but those who do, and especially those who have a practical use for such skill, should be able to do so.

POTENTIAL USES OF THE OPTOPHONE [a]

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By discussing the uses to which I have put an optophone, I plan to show how this method of reading ink-print may become an efficient tool for many blind people.

I work for the Veterans Administration teaching braille to blind and visually impaired veterans at Hines Hospital in Illinois. Formerly, I was a home teacher for the State of Illinois.

I took the 200-lesson course of training for use of the optophone. Both the course and the optophone I used were developed for the Veterans Administration at Battelle Institute in Columbus, Ohio. As yet, I have not taught the skill.

The course was completed about a year ago and since then, I have used the optophone for many little things.

I always read alone, but I had help in selecting the materials of the course, taking tests, etc.

After completing the course, a four-step procedure was evolved for developing new uses. The procedure could be terminated in success or failure at any point. Step one is to try to read or identify an item. Step two is to have someone describe the material, and I would ask him pertinent questions about it. Then, if step three were needed, I would reexamine the item using the optophone. In some cases step four was helpful. I would make a braille description of the format of the reading matter so that I could efficiently read a similar item in the future. In the case of some items like bank statements, I could simply remember the layout.

I do not claim maximum efficiency for this procedure, and it should be modified for some learners of differing abilities and backgrounds.

I found six categories of efficient uses for the optophone. A few months ago there were four, and the sub-groups are increasing each week. A pleasant surprise awaits me around every other corner. The joy of reading something for the first time more than offsets the imminent little failures along the way.

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[a] This paper was presented at The Sixth Technical Conference on Reading Machines for the Blind sponsored by the Veterans Administration, PSAS, Washington, D.C., January 27-28, 1966. A review of the Conference appears elsewhere in this issue.

It remains to define an efficient use. An efficient use is one which, after reasonable training, permits greater independence and also reduces the handicap of blindness to the individuals under consideration. I am here concerned with the things a busy person would want to read himself with a machine like the optophone.

1. Of great importance is the ability to read one's typing and to check the operation of a pen or pencil. I did this long before completing the course. It was made easier because of the foreknowledge one has of what is being read and because the likely typing errors are unlikely to be missed with the optophone. I spot-check correspondence and read all addresses and checks I write. I occasionally find an error I had no idea was present. I can read with the paper still in the machine if necessary, make corrections with all-white carbon, find my place or read what was last written. I sometimes write several checks and envelopes and then check them all. At first, it was more efficient to check an item immediately after writing it.

Formerly, our typewriter would quit working properly in the midst of a stack of Christmas cards. Now, even the slightest question as to a key struck or an item inserted into its proper envelope can be cleared up on the spot. I use raised-line checks and type them all. There is no longer the need to carry around letters and checks just to have the typing checked. My typing is improving because I can concentrate more on accuracy and because those strikeovers sound terrible.

There are those who, through carelessness or desperation, do not have their typing checked. They sometimes send blank or unsigned checks through the mail. This calls for an attitude development.

A blind typist using the optophone would not need sighted help in making corrections and could even replace the paper into the typewriter when necessary. When a blind person has much detailed work to do, sighted family members can become discouraged. As a college student, I would often wonder, "Let's see, whom should I pester with this problem?"

2. The second category is identification of currency. I identify $1, $5, $10, and $20 bills. This can be done with one hundred percent accuracy with either the Battelle instrument or the new Visotoner developed by Mauch Laboratories. The Visotoner is better for this purpose because one can scan an area almost one-half inch tall and because it is so compact and portable. Identifying money is often more necessary away from home.

Perhaps a businessman such as a vending stand operator might keep the device on a bracket within easy reach. I believe it would add to the confidence of his customers in a blind businessman if they knew that he could identify money himself when necessary. Of course, one should still use a good system of filing currency. Incidentally, blind parents would like to have their own independent means of identifying currency.

3. The third category is reading correspondence, memos, bulletins, newsletters, etc. Handwriting cannot be read with the optophone so far as we

know. It is a great pleasure and very handy to read a typed note from a friend or to read a letter from Mr. Freiberger about reading machines. In order to avail myself of that privilege, I will gladly read a carbon or Thermofax copy.

Even those correspondents who do not type may want to locate a typewriter and tap out a private note.

4. The fourth category is reading many bills, checks and bank statements, familiar forms, etc. I learn the layout of my cómmon bills and braille notes about them if necessary. For example, I read and copied the entire form of my machine-printed Earnings and Leave Statement. That was very hard to do, but now I can locate the information I want from subsequent statements in a minute.

Reading bank statements has become very routine. I can either read all the figures from the statement or else read all the checks and only a few figures from the statement. An abacus helps with the necessary calculation.

For many of my bills the cycle is now complete. I read the bill, record it in braille, write the check, read it over and mail it. Then when I receive my cancelled checks and statement, I read and take notes on it.

Here again attitudes toward responsibility and independence play a role. Some blind people pay their bills in person without having them checked. I know a blind person who paid his neighbor's electric bill. Some blind people simply discard all unsealed mail and anything that feels like an ad. If that were the policy at our house, some neighbors would be unhappy because some of their mail is mistakenly left in our mailbox.

5. A fifth use is to identify mail, packaged goods, canned goods, etc. Identification is usually more urgent than reading. I know blind people who will buttonhole everyone who comes to their door to get things read or identified. Return addresses are often easy to read with the optophone. One can read bits of ads and discard them at will. I braille the envelopes of items I have identified. Experience shows us that it is often expedient to censor items which a particular reader would not like to read. This may include religious and political material.

There are several hidden advantages to identifying things oneself. a. The time of a sighted reader may be better used for reading more lengthy materials. b. Items do not need to be moved or carried around too much, so they are easier to keep track of. c. It reduces the urgency of getting mail read and makes for a more flexible schedule.

Recently I have been gratified to find it easy to read canned goods and labels on cartons. I began to read recipes and directions also. Braille and orderliness reduce the amount you need to read. For example, with careful buying and study of features on cans, one needs to read less than one-third of the cans with the machine. Then all of the cans can be labeled (in braille) if desired.

The new Visotoner works much better for this work because much larger print can be read with it. Those big letters on TV dinner cartons and cereal boxes stand right out for the Visotoner. It is also easier to change adjustment for the size of type read, and it is easier to "roll around a can" with the Visotoner. I took the Visotoner into a supermarket and read some labels with it, and I feel that it may become practical to use it in some situations like this. The area of identification is quite new to me. I am looking for suggestions; much more may be possible in this area.

Much of what I have said shows how the optophone complements other skills, namely, braille, typing, and language skills. Orderliness aids in making its use efficient. The same can be said for the use of sighted readers.

6. I use the optophone for all I have mentioned thus far, but there is a sixth category I plan to work on—reference books. Braille is too bulky to permit most people to own a good dictionary or do reference work. The ability to use such texts in a library would be even more important. I have read the print in some of these books but have not tried to look things up as yet. Children's reference books may be a help here. Again the Visotoner, because of its shape, portability, and easy-to-use controls should be a great help. It also has a good feature for reading italicized print. The photocell array can be rotated so that the "slanted" print sounds almost like ordinary print to the ear.

I have also had a brief chance to use the Colineator which is the tracking board developed by Mauch Laboratories of Dayton, Ohio. It is marvelous and very versatile. It should help with reading books. I even enjoyed using it by using the Battelle probe against the bar of the Colineator.

There are other uses for optophones which are as yet inefficient. Nevertheless, some people may want to read magazine articles, case records, and even whole books with the instrument. My plan is to read magazine articles in order to build speed. A new motor-driven pacing aid has been built. We want to see if steady motion of the probe will aid in developing speed. This seems to have been the case for some other learners. Perhaps magazine articles will be very practical.

I made some mistakes which slowed my progress along the way. First, although I enjoyed reading articles and stories, I stopped reading them too soon, so my reading speed did not have a chance to increase. I tell my braille students to read magazines for practice after completing the course, but I did not practice what I preached. The second mistake was that when I first began to use the machine at home, I did not keep it handy enough. The machine should be available to use momentarily. The biggest problem has been the small amount of time I could devote to this work. A small problem has been some difficulty with the equipment.

Many questions are commonly asked of me. How fast do I read? I read from 5 to 25 words per minute depending on contrast, type font, context, and whether or not a tracking board is used.

Some say, "Who wants to read so slowly?" I feel that a number of people would like to do just that. Thousands of people use braille at very slow speeds. They use it for notes, addresses, and labels. Most learners of braille need to read a great deal after learning the skill in order to develop speed. This fact and my experience leads me to believe blind people may want to read some print slowly.

People also ask if it was difficult to learn. It was difficult, but some braille students work harder learning braille than I have had to do in learning the optophone. People also want to know if I have extra ability. I suppose so, but it required extra ability under the circumstances of working alone and experimentally much of the time.

I believe that with a little better optophone and improved teaching methods, this skill will be brought within the reach of many more blind people. I also believe that, like braille, this skill may best be taught by a person who uses the skill. In the case of a new skill like this, it may be even more important. A teacher must listen to the output of the machine part of the time and help the student trouble shoot. In fact, the teachers may need to learn to teach trouble shooting, scanning, and skimming if this is possible. By careful and experienced tutoring, we may be able to reduce the need for tape recordings.

We need to direct students to uses for the skill such as checking their typing at the appropriate time. I have kept samples of various kinds of print encountered in everyday use for this purpose.

We have found in teaching braille that if we introduce new uses for braille at the propitious time, motivation to "struggle on" is greatly enhanced. On the other hand, we can discourage a learner by giving him ill-timed tasks no matter how well the skill is taught.

I also feel that motivation will play a cardinal role in learning this skill, and it would be helpful if students could be promised the use of the machine if they mastered and used the skill. I hope that many a blind typist, professional worker, businessman, and housewife will find this skill of benefit. Home teachers with whom I have spoken were especially enthusiastic when they heard how I used the machine.

Much of what I have said here may apply to other "limited access" reading machines. Though the optophone affords limited access to print, it has made me feel less limited.

I cannot begin to thank everyone who helped me. They include staff members at Hines Hospital and many of you gentlemen here at the Conference.

In summary, I love to use the optophone. The pace is slow, the mileage is improving, but the payload is terrific. I would like very much to teach the skill.

PROBLEMS IN MACHINE CONVERSION OF PRINT TO "SPEECH" [a]

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Applied research that is linguistic in character is required by a variety of enterprises and institutions these days. The research to be reported here has been made under contract to the Prosthetic and Sensory Aids Service of the Veterans Administration. The Veterans Administration has supported a number of research projects for the purpose of developing reading machines for the blind; and among them have been studies in electronic instrumentation, in psychology, in linguistics, and in cross-disciplinary fields. Each of these investigations has been concerned with the problem of converting the printed word to a tactile or auditory output. Part of the general research problem is optical in nature (because print must be recognized electronically), part deals with printed-symbol-to-sensory-symbol correspondence, and another part deals with human perception of units of sounds. A specific problem area is the analysis of the structure of spoken English, in view of the fact that the printed word is speech at one symbolic remove. Since blind people in general are obliged to approach all handwritten or printed or illustrated material either through braille or through the intercession of a human reader, a reading machine of some kind is an obvious need.

Leaving the consideration of cost aside, we can assume that the best reading machine will be one that converts printed text to an output that is as much like real speech as possible. In short, the machine should talk. This ideal machine should produce completely natural sentences, and to do this it should have the ability to vary intonations and pauses appropriately for specific texts. Ideally, it should be replete with variable voice quality, such as one shade and timing of voice for business letters and another one for romantic novels—or letters! But such a perfect machine would require a gigantic storage capacity, starting with tens of thousands of words. It would also require a remarkable program to manipulate its memory, to account for all manner of related nuances: grammatical, semantic, and intonational—in order to duplicate the associational memory and variable voice

[a] Given before the XIth Annual National Conference on Linguistics sponsored by the Linguistic Circle of New York, 12 March 1966, and printed in this issue with the permission of the author.

of the human being. Bear this ideal machine in mind—and the fact that it is an *ideal* machine.

Speech has been synthesized at Haskins Laboratories and elsewhere by rules applying to very small speech units, of phonemic or syllabic size, generally. A logical developmental step was to experiment with sentence production from word units that had been pre-recorded by a human speaker. A device called the interim word-reading machine was built for the Veterans Administration at Haskins to test the feasibility of generating sentences from single spoken words. Although a successor to that machine is already under way, many of the problems encountered in the course of outfitting the first interim device with a vocabulary, and other equipment, remain; so I will confine my remarks to the machine that has already served much of its purpose, but is soon to become ancestral.

The well-named *interim* word-reading machine at Haskins deals only with the word storage, retrieval, and output side of the reading machine problem, and omits the optical scanning operation (which is not our contractual obligation). My concern has been to get words recorded for the machine's storage that can be played out one after another, to (presumably) sound like sentences. The print-scanning function has been by-passed in the machine by simulation. The contents of a printed text are typed on a Flexowriter. The punched-tape resulting is simply a letter-to-digit conversion, and this is the form of information put into the machine. This is the input.

Now about the vocabulary storage in the machine. Each separate spoken word that has been previously recorded is stored on magnetic tape, and along with each word on the tape is its digital spelling, or code. When the code for a given word is sensed on the *punched* tape by the machine, that word is searched out on the stored spoken vocabulary *magnetic* tape. The word is matched and played back if it is stored, and is recorded on another tape at the same time, where it is added to the rest of the words in the order commanded by the original text. (If the word is not stored, it must be spelled out, letter by letter, unfortunately.) When the contents of the entire text have been accumulated, this new tape, of spoken words, is played back to the listener. This is the output of the word reading machine, and the entire process is, in fact, a conversion of print to sound. I will let you judge to what degree that sound is speech-like, before back-tracking over certain linguistic problems that the tape will illustrate. The sample you will hear now is about a minute long. It will be played for you at the rate in which the individual words were originally spoken and recorded. The long words which are spelled out at the end will probably surprise you. (By this I mean that you may have trouble understanding them.)

[TAPE: PART I, "This is speech produced word by word . . ."]

That was an output of 81 words per minute, which is slow compared to normal speech—although it is not a great deal slower than my rate. This sample and the ones to follow later were compiled by a manual method, while the machine itself was still under construction; but these are the actual words from the 7200-unit vocabulary (of words, letters, numerals, punctuation, and a few suffixes) available to the machine's own storage. The original words were spoken by John T. Wadsworth, in a long series of short recording sessions made in the course of one year, for the most part.

After the words were recorded, the original tape was copied and edited. Then each word was separately mounted on a card like this one. (There are samples to be passed around.) These test sentences you have heard were generated by playing the word cards in sequence through a machine (Language Master) that plays tapes from cards instead of reels, and then each word was recorded in direct sequence on another machine. The sentences *as such* are therefore synthetic, since they were never spoken as sentences by the original speaker. The output you have heard, and those to come, demonstrate by negative evidence, that real speech is produced not word by word, but in continuous groups of words that are compatible in respect to tempo, loudness, and melody.

Every problem in applied research has constraints. For this machine, one—and only one—intonational version of each vocabulary word could be stored. This is a severe restriction, because in normal speech a given word may occur in many very, *very* different prosodic forms. Also, just one pronunciation was allowed per printed form, but homographs are a minor problem, compared to the fact that each word had to be stored in a single, frozen, stress and intonation form. It is clear that the one version recorded should be a highly probable spoken form for a highly probable type of occurrence in printed form.

We chose the vocabulary to be stored from the Dewey and the Thorndike and Lorge lists of the most frequently printed English words. There were no published data on probable spoken forms of the vocabulary words, although there were some helpful reports in the acoustic literature dealing with measurable correlates of stress and intonation by such investigators as Bolinger, Fry, and Denes.

Dr. F. S. Cooper of Haskins gave us a take-off push in the right general direction and some fine instruments to work with. We made exploratory acoustic and perceptual tests of real and synthetic speech, and approached the machine's speech problem with the hypothesis that: very frequent phrases and polysyllabic words were structurally similar in a way that might be useful for us. That is, the syllables of a polysyllabic word have a persistent stress relationship, even in varied intonational environments, and the syllables of the most frequent phrases also tend

to be regular in their stress relationships. We gradually learned something about the prosodic components of stress in words or phrases—intensity, frequency, and duration—and decided to "program" our human speaker, if possible, to make the word recordings using prescribed stresses and intonations. Now the question was, what stress to prescribe for what. We turned to the study of probability of word occurrence in printed and spoken form.

The most frequent type of phrase in English texts is prepositional. Articles, prepositions, and a connective are by far the most common English words. Most highly frequent words are monosyllabic. The stress of the most frequent words is usually very low. Most phrases begin with a preposition, as mentioned before, and most phrases and sentences end with a noun. Nouns carry much information and are generally prominent in the speech chain. And so on with the other grammatical classes . . .

We also examined so-called "intonation" and were soon convinced that it is acoustically reflected in durational shifts as well as in frequency and intensity changes. Otherwise, we knew very little except that syllables lengthen immediately before a pause, that pitch and intensity peaks usually start high and tend to decline toward the end of an utterance, and that pauses for punctuation are variable in length and of course have structural significance. (Some of these aspects of intonation almost certainly have a physiological base.)

Facts or observations of this sort, along with counts of form class sequence taken from texts in daily papers, books, and periodicals, indicated that the spoken lexicon should be recorded on the basis of a word's grammatical function. Grammatical function is correlated to some extent with word stress category, and a trained speaker could, with effort, produce words at a prescribed relative pitch, length, and loudness. An underlying assumption was that the stress prescriptions themselves would be valid, and that they would be consistently reproducible by a human speaker on demand, and over a large span of time.

Hand-out One (Fig. 1) is a diagram of probable grammatical sequences in printed texts. The size of each circle indicates the projected relative prominence of a word as a given part of speech, used in writing the stress prescriptions. Although nearly all the form classes in English can be—and often are—preceded or followed by almost any of the form classes, the arrowed lines shown between any *two* classes stand for statistical likelihood of sequence.

Using the probability rationale for the manner in which word classes were to be spoken, required that each of the 7,200 words be classified as a member of a particular grammatical class, before it could be suitably recorded. This was a stumbling block.

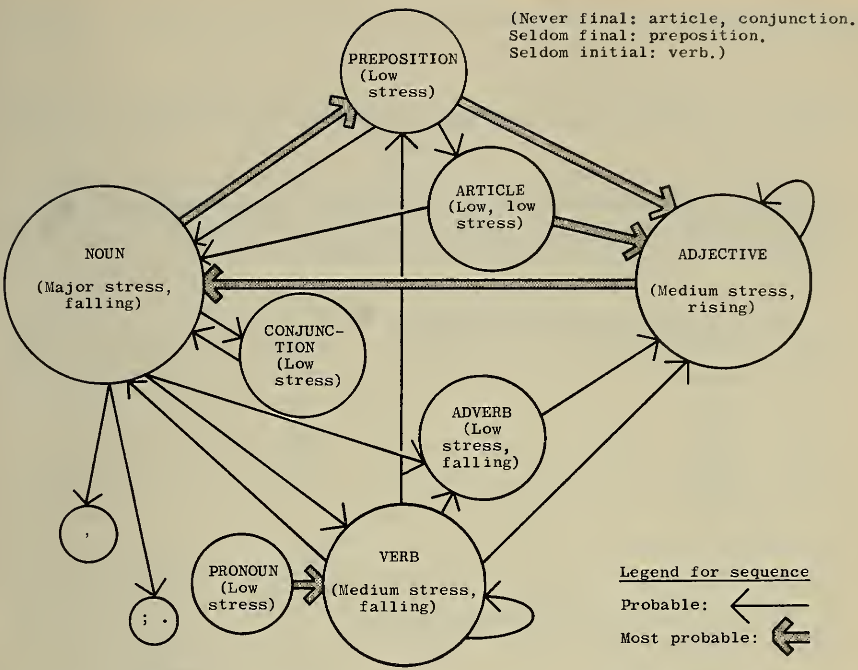

FIGURE 1. Hypothesized most probable grammatical and intonational sequences in English texts.

Hand-out Two (Table 1) suggests the problem by showing a breakdown of the thousand most frequent words by *potential* membership in a grammatical class. About half of the words can function in more than one role, and that role can be determined only by context. We therefore classified the multifunctional words by their most *probable* function, through educated guesswork and by intuition as native speakers. Impossible-to-classify words were put into the most neutral stress group, along with main verbs, whose stress in a sentence seems to be unpredictable. The prescriptions were written, and the recordings were made.

Again you may judge the output for yourselves, now bearing in mind that the sentences should be listened to not only to test the intelligibility, but also to note the words as stress types.

The recording speaker did follow the directions explicitly about 99 percent of the time, and the texts used have actually been a random test of the stored 7,200 word vocabulary. The questions to think about when listening to the tapes are: To what degree is normal intonation approximated in these tapes, and in what kinds of cases is it least normal, and finally, what *is* normal intonation?

Table 1.—*Grammatical Functions of the Most Frequent Words*

A preliminary breakdown was made of the commonplace functions possible for the 1027 most frequent words (i.e., *written* forms), as given by Dewey. The parts of speech used here as categories were Noun, Verb, Adjective, Adverb, Preposition, Connective, and Other (such as exclamatory word):

A) Words that have a *single* function,		
Nouns	196	
Verbs	140	
Adj.	81	
Adv.	48	
Prep.	17	
Conn.	8	
Other	1	
	491	
B) Words that have *two* potential functions,		
Noun or Verb	215	e.g., "being"
Noun or Adj.	120	"three"
Verb or Adj.	50	"open"
Adj. or Adv.	26	"better"
Adv. or Prep.	18	"to"
Adv. or Conn.	8	"since"
Conn. or Other	6	"though"
Adv. or Other	4	"really"
	447	
C) Words that have *three* potential functions,		
Noun, Verb, Adj.	46	e.g., "present"
Noun, Adj., Adv.	7	"first"
Noun, Adj., Conn.	3	"either"
Verb. Adj., Prep.	3	"near"
	59	
D) Words that have *four* potential functions,		
Noun, Verb, Adj., Adv.	6	"last, left, set, front, further, back"

[TAPE: PART II "Every city has its old guard . . ." Current book sample, from Zinsser's *The City Dwellers.*)

PART III "The North Wind and the Sun . . ." (well-known phonetic exercise)]

The paragraphs below have been added for readers of the Bulletin of Prosthetics Research, to compensate for their inability to hear the tapes speak for themselves.

The best feature of the interim reading machine output is the approximation of naturalistic intonation, particularly in prepositional phrases. Since phrases of this type occur far more often than any other syntactic structure in texts, the overall acceptability is high.

The most unnatural aspect of the synthetic sentences is the presently unavoidable number of spelled words, occasioned by the restriction on the size of the stored vocabulary. When, in the midst of the verbal output, the listener suddenly hears a spelled word, he is more or less bewildered and his comprehension of the sentence suffers. Spelling is not typical of either conversation or of reading and actually represents a total shift from the medium of speech to the medium of writing. Spelling is therefore destructive to the intelligibility of the whole text despite the fact that it is necessary in a mere 5 percent of the words of a normal text. In addition, the unrecorded words which must be spelled in the output are the most infrequent (i.e., least expected, least guessable) words. And they are—on the average—exceptionally long or peculiarly spelled, "difficult" words. Furthermore, each letter of a spelled word is a whole syllable, and thus the output word rate is severely slowed down by spelled words. Another handicap in spelled words is that the letters, as spoken, lack natural intonation and spacing, which a good spontaneous reader would provide if he were obliged to spell. Each of the 26 letters had to be recorded in only one intonational form, just as each of the 7,200 words was recorded in a single spoken version. Because there are even fewer restrictions on the place of letter occurrence in a word than are on the place of word occurrence in a phrase or sentence, advance prescriptions for specific letter intonation were not attempted. The letters were merely recorded in groups by rhyming syllables, e.g., "A, J, K, . . .," at a sustained single level, in the hope that in sentences they would rapidly be perceived as letters, distinct from the words spoken as units in their immediate environment. A very brief pure tone signal also precedes and follows each spelled word in the program for the output—to signal the abrupt shift from whole words to letters on the auditory track—and this seems helpful.

Studies have been and are under way to formulate a program for conversion of printed words to audible, recognizable syllables—which are in-

tended to circumvent the spelling problem. It is well-known, however, that there are few one-to-one spelling-to-sound conversions in most of the letters and syllables of English (especially where stress is concerned), so this experimental method presents problems of its own. It remains a challenge.

The second generation word reading machine now being developed, sired by the interim machine and a computer facility, will store words as control signals rather than as waveforms as at present. In that machine intonation can be manipulated and programed by synthesis, and certain of the present output irregularities in stress, timing, and inflection, will be overcome. The word rate can be speeded up as the phrasing is improved, and this is a requisite for blind listeners. At the same time our understanding of real speech phenomena will increase.

PREVENTION AND CORRECTION OF FIXED EQUINUS DEFORMITY IN MID-FOOT AMPUTATIONS

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INTRODUCTION

Mid-tarsal and tarso-metatarsal amputations are often followed by equinus and equino-valgus deformity to a degree incompatible with comfortable function (Fig. 1 and 2). Muscle imbalance progressively deforms the remaining foot, thus creating difficulties in fitting a prosthesis. The amputee is required to bear excessive weight anteriorly ofttimes across an area of scarred, adherent, tender skin.

While fixed equinus deformity is not encountered with every mid-foot amputation, its occurrence is so frequent that elective amputation at this level has been largely discarded. Nevertheless the inherent values of this amputation level, i.e., full limb length, serviceable total end bearing, and simplicity of prosthetic replacement combine to make the mid-foot amputation desirable under suitable circumstances particularly in individuals doing heavy work. A painless mid-foot amputation has been referred to as a "laborer or farm hand" amputation. It has, in fact, been most often encountered in crush injuries of the forefoot, usually industrial. The frequency of crushed forefeet in certain occupations has prompted the widespread use of workshoes with steel-cap toes as a safety requirement in certain occupations.

A number of reconstructive operative procedures have been devised to prevent and correct the ankle equinus. These include a variety of arthrodesing technics with anterior wedge osteotomy; tendon transfer utilizing peroneal and posterior tibial tendons as a sling anteriorly; anterior tibial tendon tenodesis with or without the toe extensor tendons; and astragalectomy. Certain of these operations are combined with lengthening of the tendo calcaneus. Some surgeons when confronted with this problem summarily amputate at a higher level.

During and shortly after World War II, the author had occasion to see and treat a number of young male patients with traumatic and frostbite mid-foot amputations with fixed equinus deformity and pain. It was decided to remove muscle imbalance by simple tendo calcaneus section, then manually correct the deformity and evaluate the nature of the healed

FIGURE 1. Lateral view of mid-foot amputation illustrating fixed equinus deformity.

FIGURE 2. Anterior view illustrating scar line and adverse effects of anterior weight bearing.

stump thereafter. In several cases, the response to this simple procedure was prompt, satisfactory, and permanent. It has been used occasionally in the ensuing years with continuing satisfaction. Recently, Professor B. Oscar Barry, Department of Orthopedic Surgery, Haile Sellassie I University, has advised by personal communication of his use of this simple technic in many cases of neurotrophic forefoot amputation with equinus deformity due to leprosy. He is now preparing a report of his experience.

FIGURE 3. Lateral view showing correction of equinus deformity and weight bearing during stance.

FIGURE 4. Anterior view showing correction of equinus deformity.

TECHNIC

Under sterile precautions, the tendo calcaneus is divided subcutaneously a short distance above its insertion. The ankle and hind foot are then stretched into sufficient dorsiflexion to allow the heel to rest squarely on the floor. The stump is immobilized in a cast extending to just below the knee for a period of ten days to two weeks. A walking button can be applied, and the patient may bear weight during this time if there are no contraindications. Following removal of the cast, a forefoot shoe filler or prosthetic cushion is worn in the usual manner. By this means, the equinus is corrected, and weight is borne, as it should be, on the plantar skin of the heel and remaining portion of the sole of the foot (Fig. 3 and 4). Recurrence of the equinus deformity has not been a problem. Slight calcaneus deformity may develop but will cause no difficulty either in shoe fit or as a source of pain. While push-off is, of course, eliminated, the stump even with an intact tendo calcaneus is not the source of a significant push-off in the presence of fixed equinus deformity. By this simple method, skin problems, pressure irritation, and pain associated with excessive weight on the end of the stump are largely eliminated. The weight is borne properly on the plantar heel skin and over the entire broad remaining sole area (Fig. 5 and 6).

FIGURE 5. Lateral view of patient wearing prosthesis.

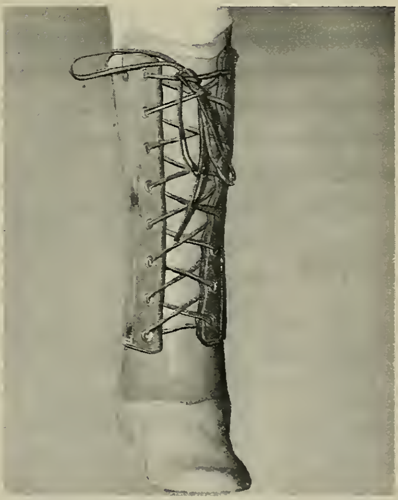

FIGURE 6. Anterior view of patient wearing prosthesis.

A SIMPLIFIED BELOW-KNEE PROSTHESIS

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INTRODUCTION

Working in an overseas situation without staff trained in prosthetics fabrication, of necessity, has caused us to develop a simple yet practical method for making a below-knee prosthesis. Although developed particularly for leprosy patients, this prosthesis has been used where there has been amputation for other indications as well.

The fabrication technique described in this paper was developed because of a great need. In this country a person must be ambulatory to live as there are no other means of transportation for the average individual. Farming is almost the only occupation and ofttimes farms are miles away from home. The only prosthetic device for amputees in the past was a kneeling peg as nothing more refined was available or even feasible in the economy. This device was highly unsatisfactory with the result that most amputees became beggars.

One factor that contributes to the success of the prosthesis described in this article is that the people really need to walk and are by nature excellent walkers. Ambulating 20 to 30 miles a day is not at all uncommon. Training to walk with the prosthesis has never been very difficult. Even in instances where we have adapted this technic to make an above-knee prosthesis for a high femoral amputation, we have always ultimately obtained satisfactory ambulation. We do not find alignment, exact length, or any

[a] Dr. Pfaltzgraff, who was educated at Elizabethtown College and Temple University Medical School in Pennsylvania, has spent most of his medical career in Nigeria. Aside from a one year furlough (1964–5) to act as Chief of Rehabilitation at the U.S. Public Health Leprosy Hospital at Carville, Louisiana, he has been in Nigeria since 1945. From 1945 to 1954, he was Medical Superintendent at Lassa General Hospital, and since that date to the present time, he has been Superintendent of Adamawa Provincial Leprosarium.

other measurements at all critical, and have seen patients satisfactorily compensate for gross misalignment and obtain good function.

Other factors contributing to the success of the prosthesis may be related to the disease itself; e.g., anesthesia is often present, but this may be of negative value in that the patient does not recognize early stump trauma. On the other hand, pain in the stump does not deter use. Also, there is often vasomotor loss with consequently little or no sweating of the stump which helps to prevent maceration and socket deterioration. On the other hand, this type of prosthesis has been provided to at least 10 patients who have had amputation for conditions other than leprosy where these factors did not apply, and yet they have been completely successful.

FACILITIES AND STAFF

Adamawa Provincial Leprosarium is the center for treatment of problem cases of leprosy for a large area in which there is a population of roughly one million. There are about 30,000 patients treated in out-patient clinics in the area, extending as far as 200 miles off. There are from 500 to 600 patients treated here annually on a permanent or temporary basis. For those needing hospitalization we have an 88-bed unit with an average census of about 60 patients.

The author is in charge of all aspects of the medical program for this unit, and nominally for out-patient care as well. Mrs. Pfaltzgraff is Nursing Supervisor, and another expatriate in the family cares for the non-medical aspects of the program. The balance of the staff is Nigerian, and almost without exception patient or ex-patient. There are about 20 medical attendants and one Nigerian Registered Nurse. Also, one patient has been trained to make prosthetic shoes and the below-knee prosthesis described herein.

TECHNIC

Since 1961 we have fitted this prosthesis to approximately 42 patients. The prosthesis lasts from 3 to 5 years, and if the fabrication is done correctly and maintenance is performed on the areas where there is friction, it should last practically indefinitely. There are 3 parts that need replacement with wear: 1. the retaining strap (if used), 2. the sole or distal tip, and 3. the socket-brim leather. One prosthesis has lasted just about 6 years. (I believe it was the first one we made for an old rather inactive man.) The patient doesn't give it excessive wear, but it has had almost no repairs at all.

Actually, many of the second prostheses we have made have been simply replacements because of improved technics, especially that related to increasing the level of the socket brim proximally to incorporate the patella and femoral condyles.

The technic used will not be described in detail as in many respects it is simply the adaptation and modification of already well-known technics.

First, the socket is made directly on the stump itself instead of making a positive and then a negative stump cast. For this reason, any alterations of pressure indicated in certain areas on the stump will need to be made by increase or decrease of pressure on the stump itself.

Where reliefs are needed in the socket, pads of cotton or felt of the desired size and thickness are fixed in areas indicated onto the stump (Fig. 1). This leaves an area of relief in the final prosthesis. Most commonly needed areas of relief are the distal end of the anterior tibial ridge and over the head of the fibula.

It is also advisable to increase the pressure in the area most suitable for weight bearing as is commonly done in the PTB prosthesis. This is accomplished by increasing pressure on the *outside* of the socket as it is being formed over the areas of the patella, the patellar tendon, and the tibial condyles. This is done by firmly bandaging a small, shaped, foam rubber pad over this area (see Fig. 5).

The socket is of the soft type with an inner layer of soft foam rubber applied to the stump over a single layer of stockinet (Fig. 2 and 3). The solid socket is developed over this by adding two layers of stockinet which are impregnated with epoxy resin (Fig. 4). This is contoured at its proximal end to cover the patella and the condyles of the femur but leaving adequate room for the hamstring tendons posteriorly on knee flexion.

FIGURE 1. Cotton pads fixed with prevulcanized latex over areas where relief is indicated.

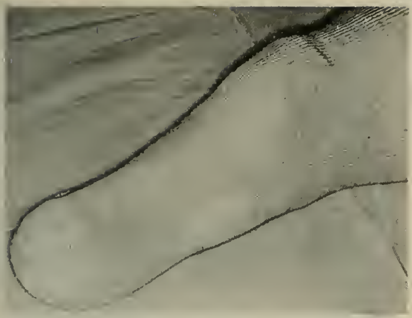

FIGURE 2. Inner layer of stockinet applied next to the skin.

FIGURE 3. Layer of ⅛-in. soft foam rubber glued to stockinet.

The socket is removed from the patient and set up in a jig using a small truncated cone of wood for the distal end of the prosthesis (Fig. 6). In this technic, the cone becomes the weight-bearing end of the prosthesis as a foot is not practical in this situation; however, a foot could easily be added as shown in Figure 16 where a SACH foot has been attached. After the socket has been fixed at one end of the jig and the peg-like prosthesis at the other end, the two are joined together with a flexible corrugated cardboard. This is then covered by two layers of stockinet which are impregnated with epoxy resin by direct application (Fig. 7). The prosthesis, which is now sturdy, can be removed from the supporting jig and fixed vertically with the socket opening downward. At this stage, two or three more layers of stockinet are added. A polyvinyl alcohol cone is now made to enclose the prosthesis, and epoxy resin is poured into the open top of the cone as in the conventional prosthetic technic (Fig. 8).

The brim of the socket is then trimmed to fit the stump allowing for the hamstring tendons posteriorly (Fig. 9), and a narrow leather cuff is cut and fixed to the brim of the socket to prevent undue wear (Fig. 10).

In many instances, especially if the stump is long, a simple friction fitting is adequate to retain the stump in the socket. No stump socks are worn. This is not, however, a true suction socket as the inner surface which is

FIGURE 4. Application of epoxy resin on two layers of stockinet.

made up of the ribbed surface of stockinet is not smooth. We have found that amputation should preserve as much length as possible. A well-planned amputation just proximal to the malleoli is much simpler to fit than a Syme's amputation and, in fact, is the type of stump most easily fitted with this type of prosthesis.

FIGURE 5. Snug bandaging of impregnated stockinet incorporating prepatellar pressure pad.

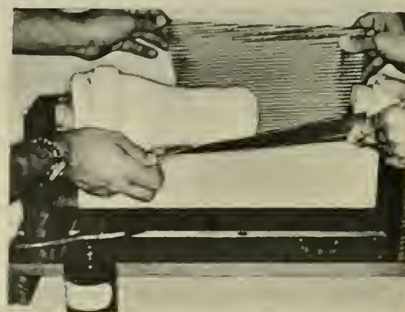

FIGURE 6. Socket and distal wood cone set up in jig.

FIGURE 7. Application of epoxy to outer shell.

FIGURE 8. P.V.A. cone providing outer finish to prosthesis.

FIGURE 9. Trimming socket brim.

FIGURE 10. Cutting leather cuff for socket brim.

If friction between the stump and socket will not retain the prosthesis, a supporting strap must be affixed. This is done by inserting sheet metal screws with rather large heads into the prosthesis about 1½ in. distal to the brim and parallel to the lines of the hamstring tendons (Fig. 11). An elastic rubber band (Fig. 12) is attached to these two screws (we have been using discarded inner tubes to make the rubber strap). This strap passes from the medial screw across the popliteal space laterally and superiorly, crossing proximal to the patella, and then passes inferiorly and laterally and is attached with slight tension to the lateral screw head (Fig. 13).

The distal end of the prosthesis is completed by cutting to the correct length and affixing a piece of car tire rubber to it with rubber cement and a few nails (Fig. 14 and 15).

Figure 16 shows a cross section of the completed prosthesis.

When it is necessary to alter the socket due to stump shrinkage, it is accomplished by filling in the void with a mixture of prevulcanized latex and cork dust or with a silicone rubber. A length of stockinet is pulled over the stump and the filler is poured into the socket, the stump is inserted, and the patient walks on the prosthesis until the filling material sets. This new layer of stockinet is thus incorporated into the prosthesis, and a new leather cuff must be fitted on the brim.

FIGURE 11. Inserting screws for supporting strap.

FIGURE 12. Attachment of supporting strap.

FIGURE 13. Posterior view showing detail of supporting strap.

FIGURE 14. Attaching tire sole to distal end.

FIGURE 15. Trimming sole rubber.

DISADVANTAGES

The following are some of the problems that arise with the preparation and use of this prosthesis:

1. The development of ulceration from overuse at the beginning. Since many stumps are anesthetic, there is a tendency to misuse or overuse the prosthesis. This causes early breakdown of critical areas such as over the head of the fibula, areas around the brim of the socket, and the tip of the stump. Further tissue breakdown may occur because of stump shrinkage.

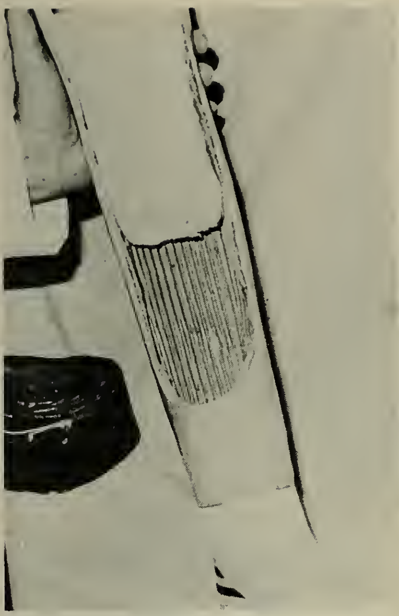

FIGURE 16. Cross section of completed prosthesis.

2. The danger of misuse of epoxy resins in following this technic, especially when making the socket on the stump. The socket must be made snug without producing a break in the skin, the heat of the epoxy catylization must not burn the stump, and an accurate fit must be obtained.

3. The expense of epoxy resins. A much cheaper prosthesis could be made with polyester resins; however, we have not been able to utilize polyesters due to their instability in a tropical climate.

4. There is the potential danger that with the easy availability of a simple prosthesis, amputation is resorted to too readily. In leprosy, amputation should only be a last resort and there are many conservative measures which are indicated, both surgical and nonsurgical, before amputation should be elected.

ADVANTAGES

The merits of this prosthetic technic are:

1. It is inexpensive. The prosthesis can be manufactured from materials costing approximately $5.00 to $10.00 depending upon the source of supply.

2. The simplicity of production (Fig. 17).

   a. The technic is simple and easily learned. We have been able to successfully teach this technic to an African who knows no English but is quite clever with his hands.

   b. It requires no expensive tools or equipment.

   c. A prosthesis can be completed in 5 to 7 hours total working time.

3. Durability. Except for the leather socket edge, the rubber sole, and the supporting strap, many prostheses have needed no repairs after 4 or more years of hard use. The three repairs listed can all be done by an entirely untrained person.

4. It is completely practical.
   a. It is lightweight, averaging 3 to 4 lb.
   b. The training period has been usually negligible. In some instances, patients have donned the prosthesis and walked off immediately with a relatively good gait, and no other support, even though they had never previously worn a prosthesis (Fig. 18 and 19).
   c. A rapid, yet accurate and simple method has been devised to make alterations to the socket when stump shrinkage occurs. It should be noted that alterations to care for increase in stump size are much more difficult, and except for minor alterations it becomes simpler to make a completely new prosthesis.

Figure 17. Patient showing mid-calf amputation and prosthesis.

Figure 18. Prosthesis donned by patient.

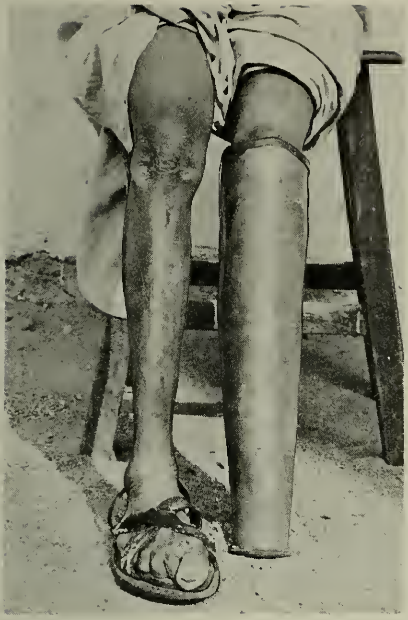

FIGURE 19. Photo shows sandal with microcellular rubber insole provided for all patients with anesthetic feet.

SUMMARY

A simple, economic below-knee prosthesis is described that is practical for use where professional prosthetic facilities are not available. The technic for making this prosthesis is outlined briefly and relative disadvantages and advantages are covered. It is shown that the chief problems encountered are the result of overuse and misuse of the prosthesis, because many stumps are anesthetic, and improper use of epoxy resins. Some of the advantages of this prosthesis are its low cost and simplicity to produce, its light weight, and its durability.

EVALUATION OF THE HEIDELBERG PNEUMATIC PROSTHESIS

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FOREWORD

The research described in this report, *Evaluation of the Heidelberg Pneumatic Prosthesis,* by Luigi Lucaccini, Roger Wisshaupt, Hilde Groth, and John Lyman, was carried out under the technical direction of John Lyman and is part of the continuing program in upper-extremity prosthetics research.

This project is conducted under the sponsorship of the Veterans Administration and is submitted in partial fulfillment of Contract Number V1005P–9779.

ABSTRACT

This paper presents the results of an engineering and performance analysis conducted on an upper-extremity prosthesis developed at the University of Heidelberg, Germany. This prosthesis provides bi-directional movement around three axes (at the elbow, wrist, and hand) and is externally powered by a portable and rechargeable CO_2 source.

Engineering tests provide data regarding the speed of movement of the various components, the forces available from these components, the mechanical reaction times of these components, the characteristics of the prosthetic control system, and a brief description of the mechanical operation of controls and components.

Performance tests were conducted on two subjects: (a) a standard above-elbow amputee, and (b) a forequarter amputee. Data from these tests include the ranges of operation of the prosthetic components achieved by the amputees, their speed in initiating the various movements of the prosthesis, their precision of motion, and their performance on a series of standardized tasks under normal and stressing conditions.

INTRODUCTION

The results of an engineering and performance assessment study of the Heidelberg Pneumatic Prosthesis conducted at the Biotechnology Laboratory, University of California at Los Angeles are given in this report. The Heidelberg Pneumatic Prosthesis represents an important milestone in the development of artificial arms since it can be considered the first practical externally powered prosthesis. Earlier attempts substituting auxiliary power for conventional muscle power led only to construction of several prototype models, as for example the IBM electric arm or to a limited number of individual units as in the case of the French electric hand.

The Heidelberg prosthesis can be used as a hybrid system with conventional and pneumatically driven functions or as a complete externally powered system. This flexibility makes it useful for amputees at all levels of disability, although the greatest rehabilitative value of the prosthesis will be for the severely handicapped. For these patients, satisfactory substitution of lost functions is hardly possible with conventional body-powered systems and an external energy source is expected to aid in reducing effort and fatigue during operation.

The pneumatic arm provides the same functions as conventional prostheses but in addition permits active wrist rotation, adding to its utility.

The relatively wide acceptance of the pneumatic prosthesis in Europe and the interest expressed in this country were the prime reasons for conducting a controlled laboratory study and assessing its functional and engineering characteristics. Similar studies have been conducted on other externally powered devices such as the AIPR Pneumatic Prosthesis, the French electric hand, the Yugoslav electronic hand, and the Northwestern University electric elbow.

Various phases of this assessment study have been in progress since 1961 when this prosthesis was first obtained from the University of Heidelberg. Delays were imposed by several unforeseen events. On two occasions the arm was returned to Germany, once for replacement of the elbow bellows and again for an overhaul of the control valves. All replacement parts had to be obtained from the University of Heidelberg since no parts were commercially available. Waiting periods and experimental "downtimes" were therefore very long. Performance testing was completed late in the spring of 1964 and was followed by the engineering tests.

The study follows the general procedure outlined by Groth, Lyman, and Kaiser (1963), and is based on the "semi-case study" approach. Several phases of the evaluation have drawn heavily on earlier work in the area of prosthetic evaluation. Specifically to be mentioned in this regard are studies by Blaschke, Gottlieb, Jampol, and Taylor (1949), Gottlieb and Lyman (1951), Gottlieb, Santschi, and Lyman (1953), and Kay and Peizer (1958); and papers by Fishman (1954) and Groth and Lyman (1956).

The report is divided into three parts. In Section I, results of the engineering tests are presented along with a physical description of the Heidelberg Prosthesis (hereafter also referred to as the experimental arm). Section II contains the results of performance tests obtained on two amputee subjects using the experimental arm along with similar data wherever applicable for one of the subjects using a conventional American above-elbow prosthetic arm. Conclusions and recommendations regarding the experimental arm are presented in Section III.

I. ENGINEERING EVALUATION

A. System Description

1. Physical Configuration

The complete Heidelberg prothetic arm has the following three basic components which form the active system: (1) the upper arm, (2) the lower arm, (3) the terminal device (TD). The upper and lower arm shells are fabricated of conventional plastic materials.

The configuration used in this study was chosen to be representative of a variety of options available for various amputation levels and various user occupation groups. Comprehensive surveys of these options have been provided by Marquardt (1963) and Marquardt and Haefner (1957).

a. Upper Arm. No active components used in the operation of the powered articulations are contained in the upper arm. It is terminated distally by an end plate with holes arranged for the mounting of the lower portion of the arm.

b. Lower Arm. This part is connected to the upper arm by means of a threaded pin located proximally in the upper end of the elbow mechanism. Figure 1 illustrates the lower arm and terminal device. Flexion and extension functions are provided by the elbow through the inflating and exhausting of a bellows. The elbow locking mechanism which consists of a bellows, locking pin, and spring is located inside the lower arm adjacent to the elbow mechanism. The elbow unit and elbow locking unit are illustrated in Figure 2. Figure 3 illustrates the wrist rotation unit which operates through the combined action of a bellows and return spring. Next to the wrist rotation unit but not shown is the wrist locking mechanism which operates in a manner similar to the elbow locking unit.

c. Terminal Device. A sculptured wooden hand is connected to the lower arm wrist unit with an axial shaft. The articulated thumb closing toward the index finger is activated by a bellows and spring inside the hand permitting the thumb to be locked at any desired position. The distal ends of the thumb, index finger, and second finger are equipped with small rubber pads to aid prehension (Fig. 4).

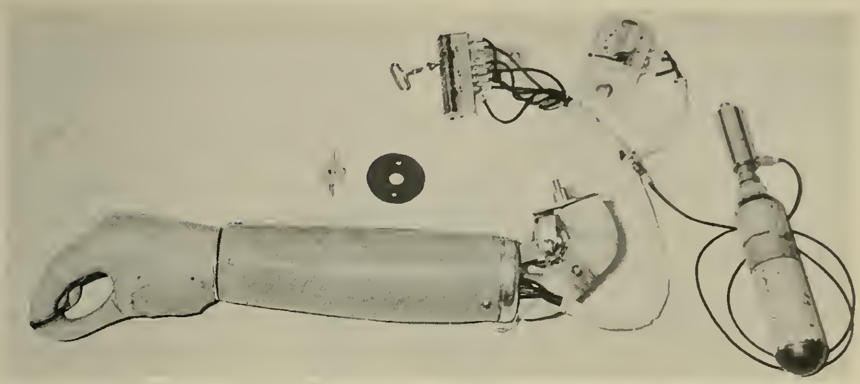


FIGURE 1. Heidelberg Pneumatic Prosthesis. Photograph includes elbow bellows, lower arm, terminal device, gas bottle and screw-in regulator, 7-position control valve, 4-position control valve, washer, and wing nut.

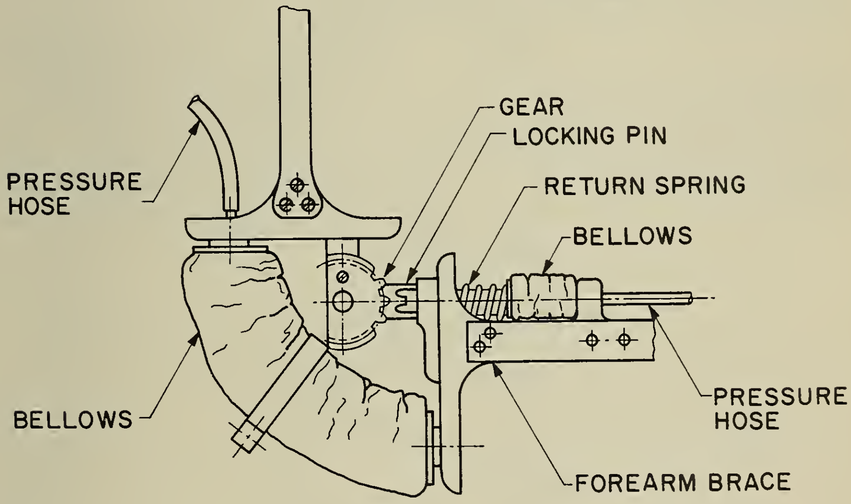


FIGURE 2. Elbow unit.

2. Power Source and Linkage

The Heidelberg arm is gas powered and designed to be operated from a portable compressed CO_2 source, a small pressure cylinder filled with liquid CO_2, and connected to a regulator adjusting the operating pressure. The portable cylinder is recharged by connecting it to a large CO_2 tank using a special valve and reduction fitting obtained commercially. Problems arising for the amputee from this procedure will be discussed in Section I.B.4.d.

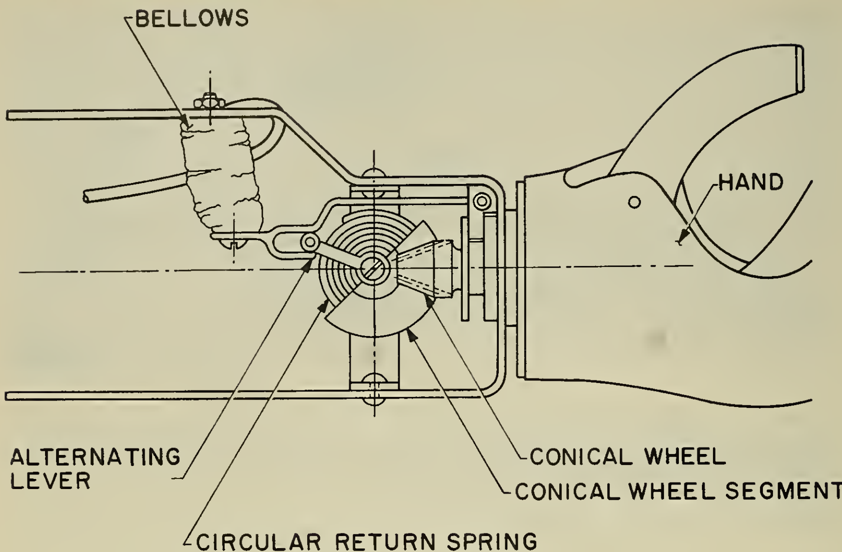


FIGURE 3. Wrist unit.

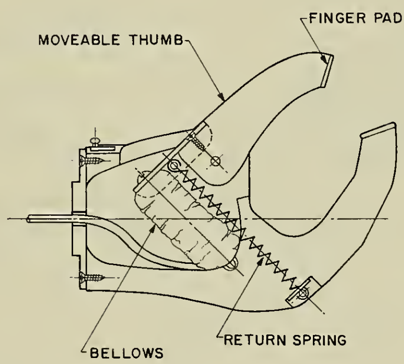


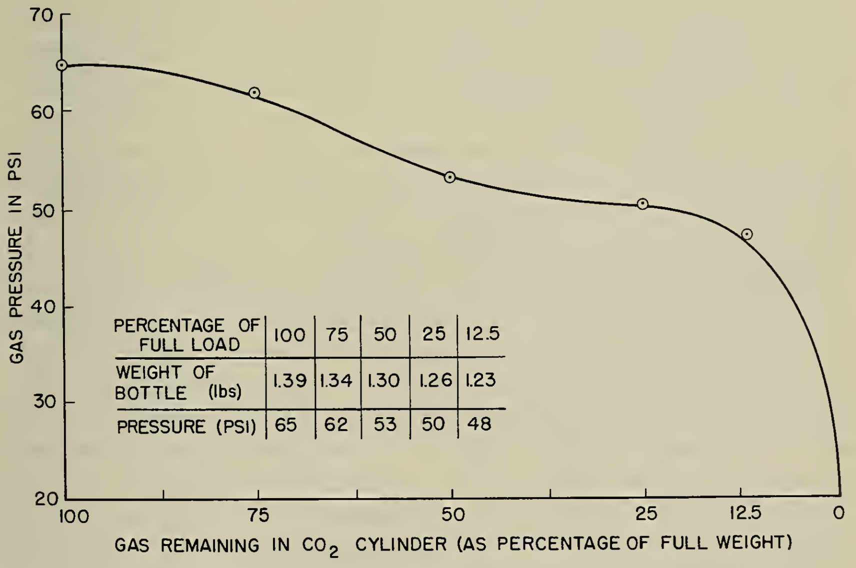
FIGURE 4. Pneumatic hand.

The German cylinder supplied with the arm had a built-in regulator; however, it was made of aluminum and did not meet the United States standards for high pressure gas containers. It was replaced by an equivalent size steel cylinder with a screw-in regulator that was commercially available. The weight of the empty steel cylinder with regulator was 1.22 lb. as compared to 0.46 lb. for the original aluminum device. The capacity of the steel cylinder was 0.17 lb., whereas the capacity of the aluminum cylinder was estimated at 0.26 lb. (taking into account the volume difference). As a consequence, the gas represented 12.2 percent of the total weight in the case of the steel cylinder versus 36.1 percent for the aluminum cylinder.

All the performance assessment data in this report were collected while using the steel cylinder and screw-in regulator, with operating pressure adjusted for 65 p.s.i. with a full cylinder. In spite of the regulator, a significant drop in pressure occurred during the use of the gas supply. Figure 5 presents this change in available gas pressure as a function of gas remaining in the cylinder. Since the gas pressure is directly related to the operational performance of the prosthesis, it was decided to conduct all engineering tests at three discrete pressures. These were selected to be representative of the pressures that could be expected in normal use of the arm with the steel cylinder and screw-in regulator. The values chosen were 45, 55, and 65 p.s.i., corresponding to 10, 60, and 100 percent of full gas weight in the steel cylinder (cf. Fig. 5).

The arm was found to operate equally well from a large laboratory CO_2 tank equipped with an adequate regulator or from a standard laboratory compressed air supply with regulator. Tests of the elbow mechanism showed that at 65 p.s.i. there was no significant difference in the operation of the arm when either CO_2 or compressed air was used. Compressed air was chosen for engineering testing for convenience, repeatability, and availability of a good quality regulator.

The linkage from power source to control valves and from control valves to functional prosthetic parts was a small diameter rubber tubing (0.04 in. ID). This small tubing size serves also to damp the operation of the arm. The importance of this damping function was demonstrated by connecting the power source directly to the bellows.



PERCENTAGE OF FULL LOAD	100	75	50	25	12.5
WEIGHT OF BOTTLE (lbs)	1.39	1.34	1.30	1.26	1.23
PRESSURE (PSI)	65	62	53	50	48

FIGURE 5. Change in gas pressure with depletion of power supply.

3. Control System

Prosthesis control is achieved by the use of a set of on-off valves. Two valves, at least, are necessary for antagonistic functions, such as prehension, motion A and release, motion B. One valve connects the powerline to the bellows, permitting the inflation necessary for motion A when opened. A second valve exhausts the bellows by opening it to the atmosphere, thus allowing the reverse movement, motion B, of the prosthetic component by return spring or gravity as in the case of elbow flexion. Other valves are concerned with locking and unlocking functions. Construction of the valves is based on the use of ball-type pressure greasers modified for this purpose. Activation of the individual valves within a control is achieved by a multiple sector camshaft or by successive sections on a lever. The operation of the cam and valve complex is described in Section I.C.

B. Basic Mechanical Characteristics

1. Available Ranges of Motion

Antagonist movements of the arm receive power only for one motion, and the opposite motion is passive. Passive movement is produced either by the action of a spring compressed in the active phase or by gravity as in the case of elbow movement. Active or passive power control, pressure of the power supply, and external load will determine the operating characteristics for each function. The experimentally determined operating characteristics should be represented by a three-dimensional surface whose coordinate axes would be operating pressure, time, and angular deflection of displacement. Such a diagram would have to be constructed for each condition of external load. However, a representation of this kind would be too complex to be of practical value and a more limited approach was used. For each load condition, chosen to be representative of the range the arm can handle, a set of recordings was made showing displacement as a function of time at the three pressures. Using these curves and the diagram of pressure as a function of gas remaining in the bottle (Fig. 5), one may determine the performance characteristics of any component of the arm over the range of available pressure.

a. Elbow Range. The elbow has 10 locking positions about 9 deg. apart from each other, providing a range of motion of 81 deg. from upper to lower locking positions. It is possible to move the arm beyond the extreme locking position and extend this range slightly. The elbow locking mechanism was disconnected during testing of range of motion. Results of these tests are illustrated in Figures 6 and 7. A zero reference position was arbitrarily chosen as the position of the elbow in full extension with a load of 0.625 lb. at 65 p.s.i. The zero reference corresponded to an angle of 20 deg. with the vertical. The mounting of the forearm and application of loads was identical to that described in Section I.B.2.a. Ranges of motion

under the various loading and pressure combinations are presented in Table 1 in terms of this arbitrary reference point. A significant decrease in range occurred either when pressure was reduced or load increased.

TABLE 1.—*Range of Elbow Unit, Loaded and Unloaded, for Three Gas Pressures*

Gas pressure (p.s.i.)	No load	0.625 lb.	1.25 lb.	2.00 lb.
45	+4/+91	0/+82	−2/+74	−2/+62
55	+4/+94	0/+86	−2/+79	−2/+69
65	+4/+96	0/+90	−2/+83	−2/+74

NOTE.—All values are in degrees.

b. Wrist Range. The wrist unit has 18 locking positions, 12 deg. apart from each other. The no-load range extends about 3 deg. on each side of the extreme locking positions. A constant torque loading was not considered representative of the normal loading conditions that would occur during use by amputees. Thus, to investigate the functional adequacy of the wrist unit the forearm was kept at a position of 90 deg. with regard to the upper arm, and two aluminum cylinders (1.5 in. diameter, 4 in. long, 0.75 lb.; 1.5 in. diameter, 8 in. long, 1.49 lb.) were used as loads. These cylinders were held in the terminal device so that the center of gravity of the cylinder coincided with the axis of rotation of the wrist mechanism. Size and weight of the large bar were experimentally determined so as to render operation of the wrist impossible for supination under the lowest operating pressure (45 p.s.i.). The zero reference point was defined as the position of the wrist in supination at 65 p.s.i. with no load. Experimentally determined values for wrist rotation range of motion are presented graphically in Figures 8 and 9. These results are summarized in Table 2. It should be noted in Table 2 that the range obtained at 45 p.s.i. with 1.49 lb. load was determined only for pronation since supination was not possible in this case. It can be seen from Table 2 that range of wrist motion was not altered appreciably over these combinations of load and pressure employed in testing.

TABLE 2.—*Range of Wrist Unit, Loaded and Unloaded, for Three Gas Pressures*

Gas pressure	No load	0.745 lb.	1.49 lb.
45	0/+210	0/+210	−5/+205
55	0/+210	0/+210	−5/+205
65	0/+215	0/+210	−7/+203

NOTE.—All values are in degrees.

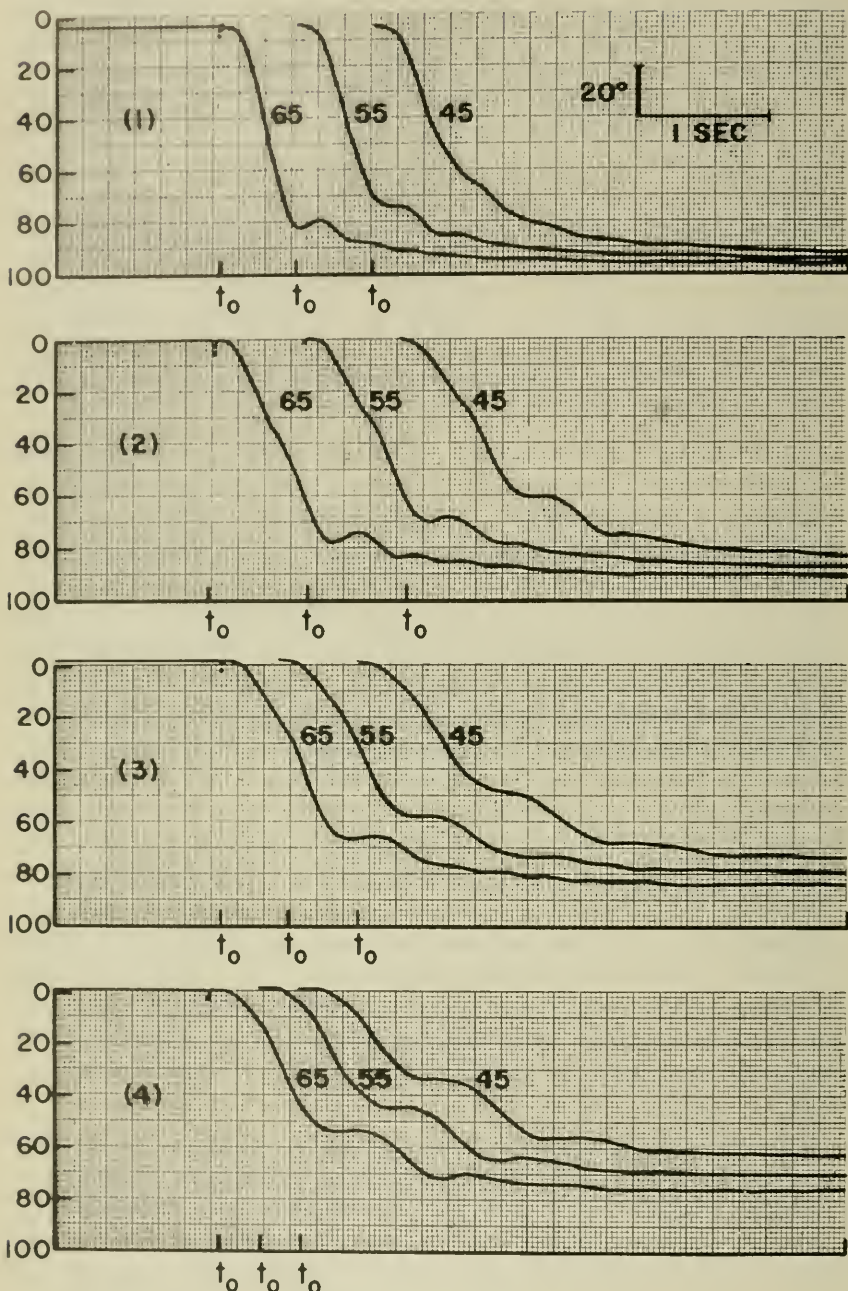


FIGURE 6. Flexion curves for elbow unit. Curves for gas pressures of 65, 55, and 45 p.s.i. are superimposed for (1) no load, (2) 0.625-lb. load, (3) 1.25-lb. load, and (4) 2.50-lb. load.

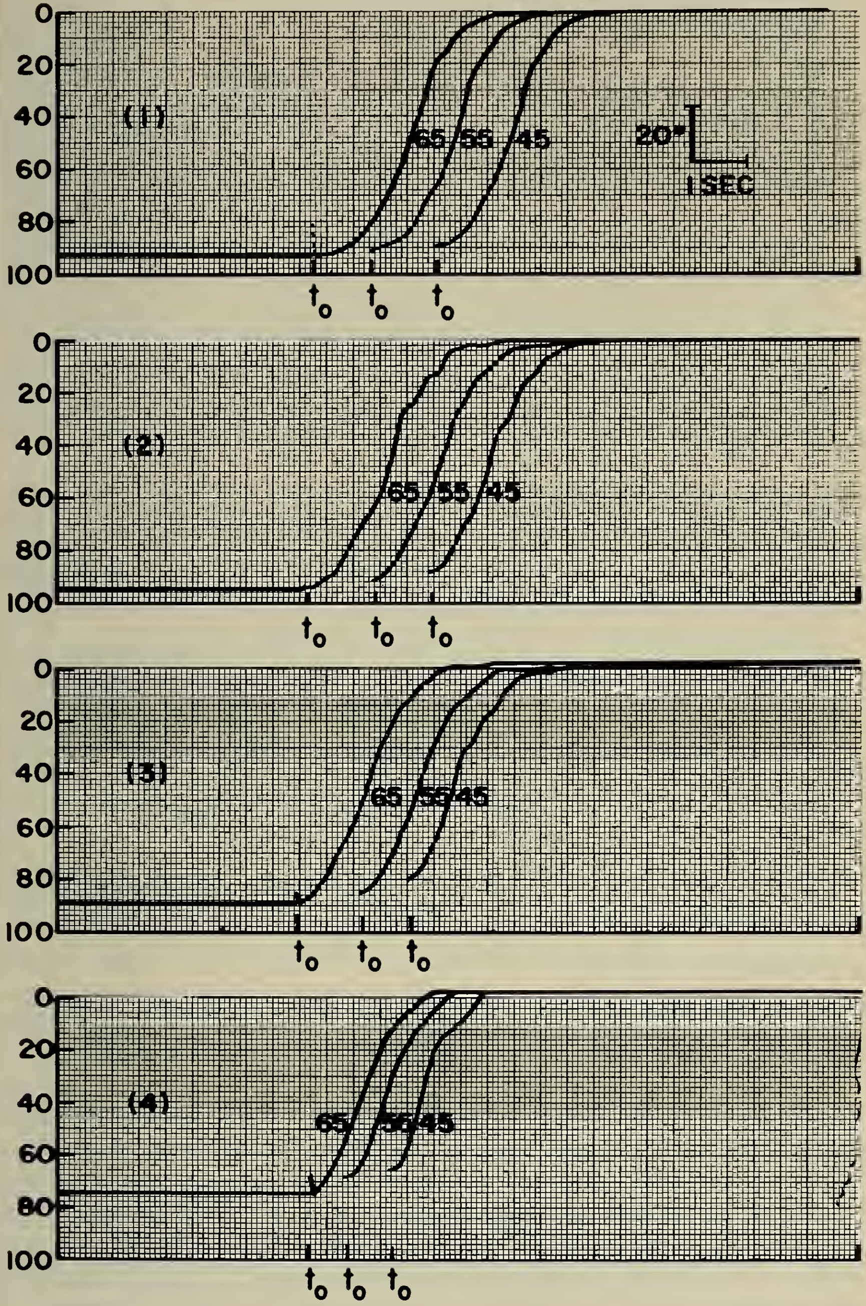


FIGURE 7. Extension curves for elbow unit. Curves for gas pressures of 65, 55, and 45 p.s.i. are superimposed for (1) no load, (2) 0.625-lb. load, (3) 1.25-lb. load, and (4) 2.50-lb. load.

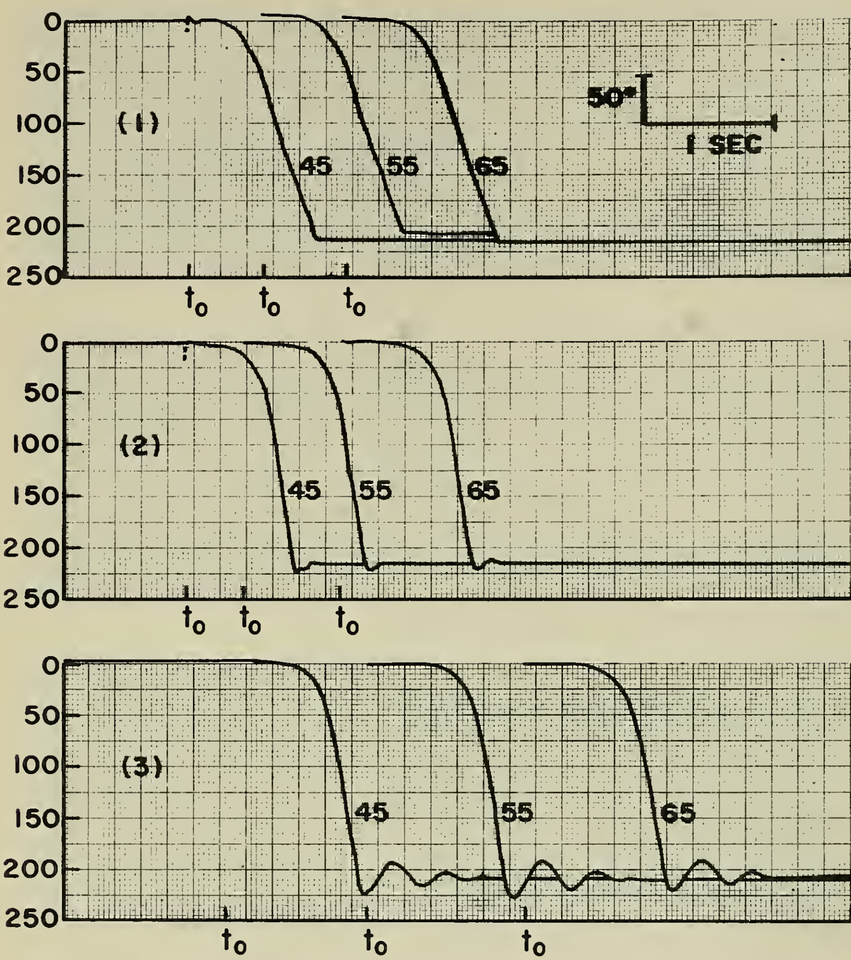


FIGURE 8. Pronation curves for wrist unit. Curves for gas pressures of 65, 55, and 45 p.s.i. are superimposed for (1) no load, (2) 0.745-lb. load, and (3) 1.49-lb. load.

c. Terminal Device Range. The terminal device has no fixed locking positions but can be locked by friction anywhere along its range of motion. There was no readily apparent technique for simulating a variable load on this unit, nor was the practical application of such a condition apparent; therefore, the operation of the terminal device was investigated without loading. In all cases a maximum range of motion of 45 deg. deflection was obtained except for closing at 55 and 65 p.s.i. which showed an additional degree of deflection. This was due to the compression of the rubber pads on the thumb and finger which disappeared when the valve was closed. The curves for this test are shown in Figures 10 and 11.

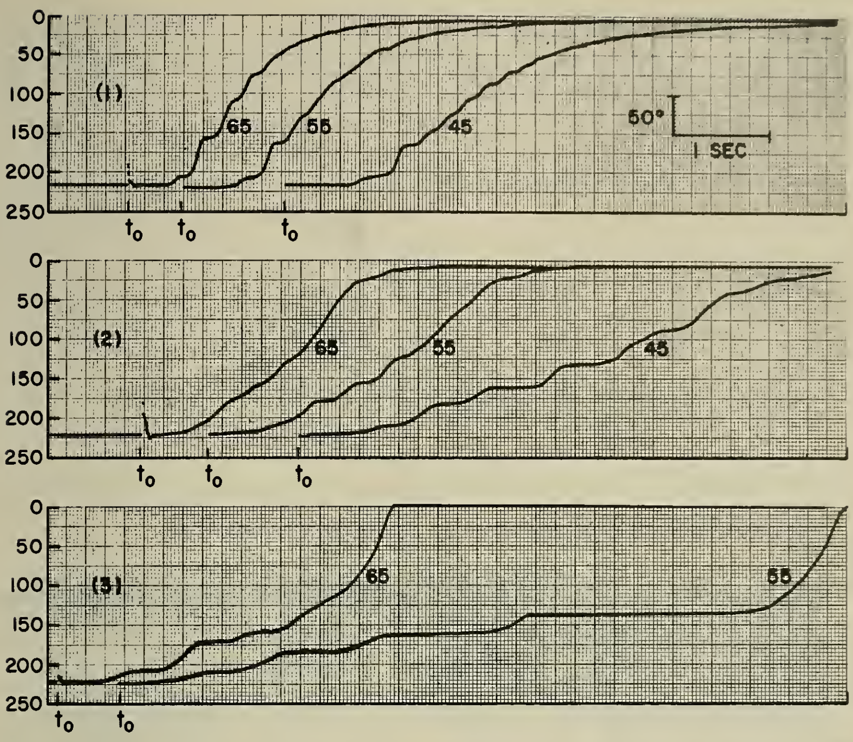


FIGURE 9. Supination curves for wrist unit. Curves for gas pressures of 65, 55, and 45 p.s.i. are superimposed for (1) no load, (2) 0.745-lb. load, and (3) 1.49-lb. load. No movement of wrist occurred with 1.49-lb. load at 45 p.s.i. gas pressure.

2. *Available Forces*

a. Stalling Force of Elbow. The prosthesis with upper arm removed was mounted at the proximal end of the elbow mechanism to a horizontal mounting plate. Forces were applied to a point on the terminal device at 14.5 in. from the axis of elbow rotation. The forces always acted in the vertical direction and were experimentally increased until elbow flexion was prevented upon application of power to the arm. Four measurement positions were chosen. These were the extreme lower (0 deg.) and upper (90 deg.) positions of the elbow, and two intermediate positions at about 30 deg. and 60 deg. The zero reference was the same as described in Section I.B.1.a, 20 deg. from the vertical. Figure 12 presents stalling force of the elbow unit as a function of gas pressure and angle of flexion. These data are summarized in Table 3.

Since the extension movement of the arm is essentially a passive function achieved by exhausting of the elbow bellows, the resulting force is the vertical component of the weight of the forearm plus the weight of the

terminal device and any external load. The same force application point and flexion angles as for the flexion test were used to measure the extension force of the arm. These forces were found to be 0.50, 0.60, 0.70, and 0.75 lb. for test angles 0, 30, 60, and 90 deg. respectively.

TABLE 3.—*Maximum Weight Lifted by Elbow Unit for Three Gas Pressures*

Gas pressure (p.s.i.)	Position of elbow			
	0°	30°	60°	90°
45	6. 80	3. 90	2. 10	1. 05
55	8. 30	4. 75	2. 60	1. 35
65	10. 00	6. 45	3. 10	1. 65

NOTE.—All values are in pounds.

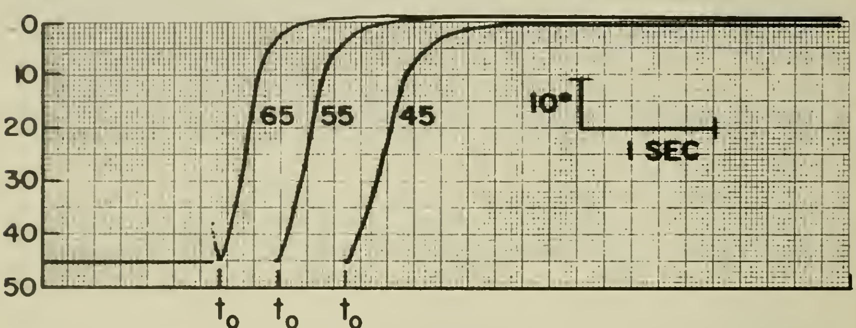


FIGURE 10. Closing curves for terminal device. Curves for gas pressures of 65, 55, and 45 p.s.i. are superimposed.

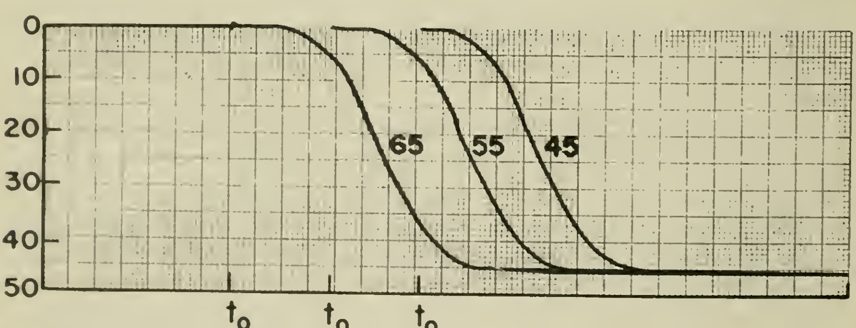


FIGURE 11. Opening curves for terminal device. Curves for gas pressures of 65, 55, and 45 p.s.i. are superimposed.

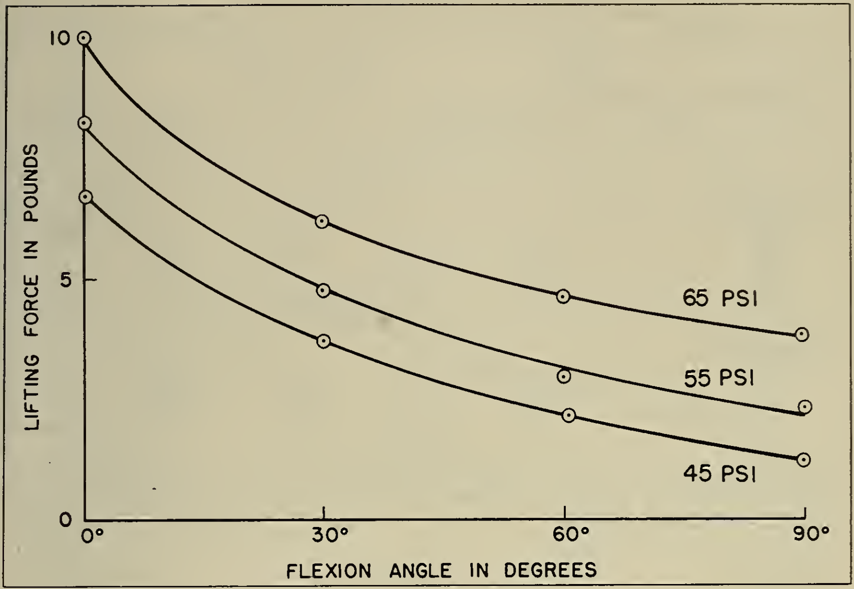


FIGURE 12. Stalling force of elbow unit as a function of flexion angle.

b. Stalling Force of Wrist. These values were determined by applying a stalling torque to the wrist unit through a 4-in. lever of negligible weight attached to the terminal device. The angular zero reference point was defined as the position of the hand in supination at 65 p.s.i. with no load. Stalling torques were determined for both directions at five test positions: 0, 60, 120, 180, and 210 deg. (from full supination to full pronation). The results of these tests are presented in Figures 13 and 14, and are summarized in Table 4. Inspection of these results shows that pronation is far more powerful than supination, and the pronation force is highest in the center of the range of wrist motion while the supination force increases linearly from 0 deg. to 210 deg.

c. Terminal Device Prehension Force. Prehension force was measured with a force indicator adjusted to one of four widths: 0.525, 1.00, 1.45, and 1.95 in. Results were obtained at these openings for the three gas pressures described previously. Figure 15 illustrates these results, which are also summarized in Table 5.

TABLE 4.—*Maximum Forces of Wrist Unit for Three Gas Pressures*

Gas pressure (p.s.i.)	Position of wrist				
	0°	30°	90°	150°	210°
Pronation:					
45	0. 80	0. 85	1. 10	1. 00	0. 90
55	1. 10	1. 25	1. 30	1. 40	0. 90
65	1. 25	1. 80	1. 75	1. 60	1. 10
Supination:					
45	0. 25	0. 30	0. 40	0. 55	0. 75
55	0. 25	0. 27	0. 35	0. 50	0. 65
65	0. 25	0. 25	0. 30	0. 45	0. 55

NOTE.—Forces are in pounds. Torques can be obtained by multiplying by 4 (inches) to give values in inch-pounds.

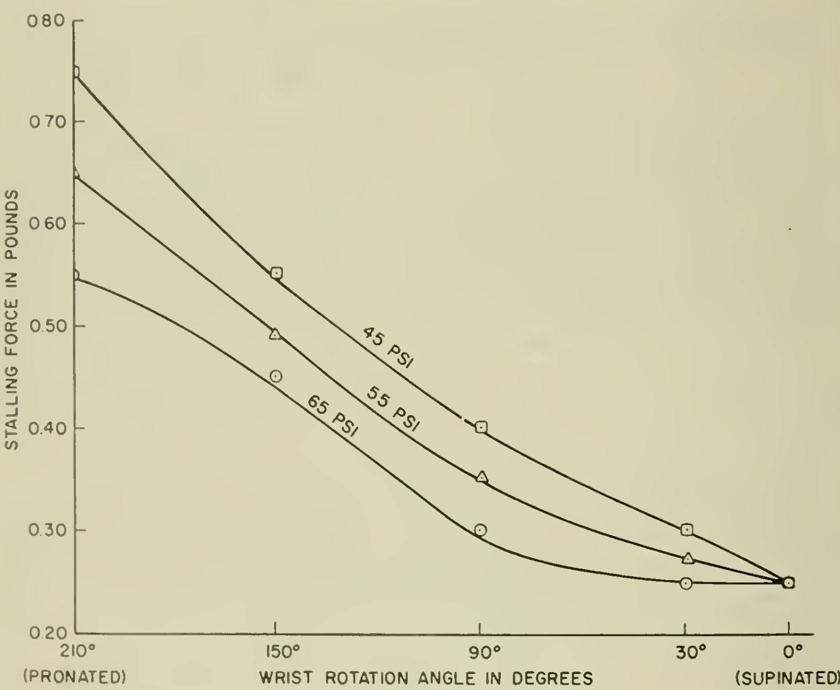


FIGURE 13. Stalling force of wrist unit (supination).

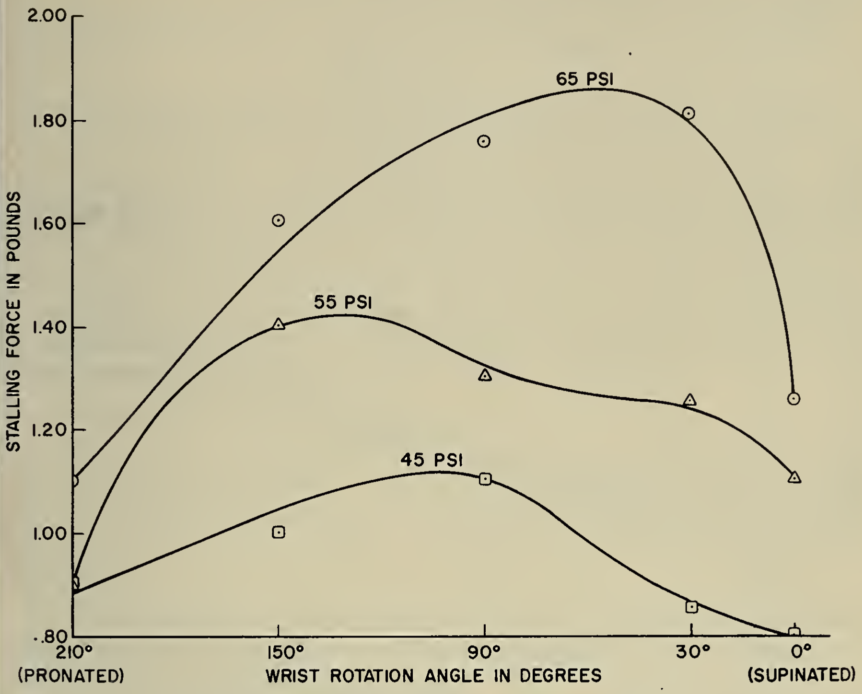


FIGURE 14. Stalling force of wrist unit (pronation).

TABLE 5.—*Terminal Device Prehension Force for Three Gas Pressures*

Gas pressure (p.s.i.)	Terminal device opening			
	0.52 in.	1.00 in.	1.45 in.	1.95 in.
45	8.4	9.5	11.8	15.0
55	13.1	13.5	14.0	17.5
65	15.6	17.8	18.5	22.0

NOTE.—All values are in pounds.

3. *Mechanical Time Lags and Velocities*

In this section the movement durations determined by the mechanical systems of the arm are discussed. "Time zero" is defined as the instant at which gas pressure was applied to the respective motor device or the instant at which the same unit was open for exhaustion of gas to the atmospere. The time intervals necessary for manipulation of control valves and the effect of locking mechanisms were neglected in this phase of testing. Separation of unlocking from activation of the motor unit would be tedious.

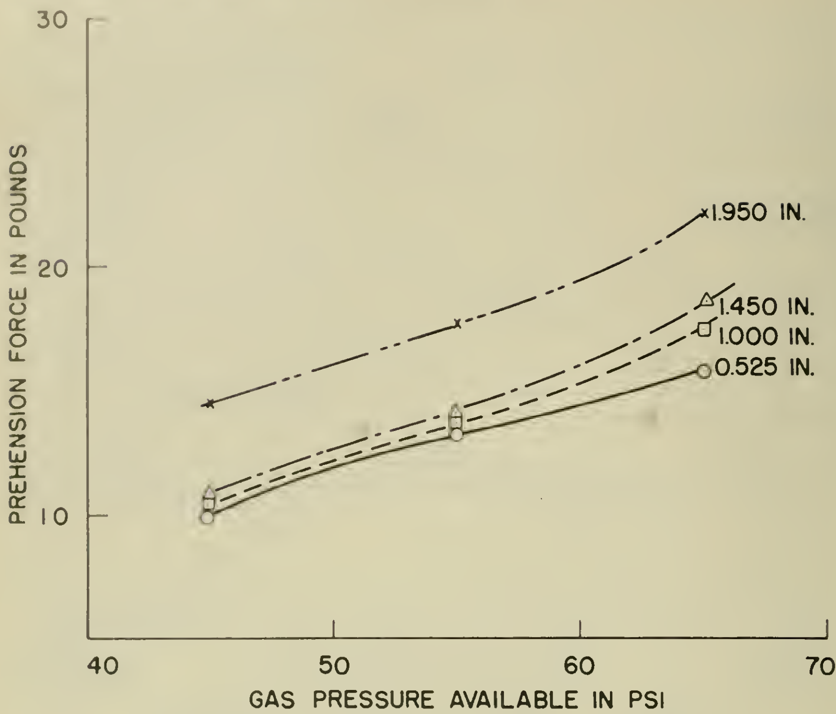


Figure 15. Terminal device prehension force as a function of gas pressure and size of opening.

Also, the activation of the control valves depends not only on the design of the valves but also on the amputee's method of activation. Thus a "standard" method of activation is a matter of choice, and inclusion of such a method would only introduce irrelevant variability into these measurements. In these tests the normal control valve was bypassed by keeping it open to the desired function, and an electromagnetic valve was inserted in series with the control valve. This valve was opened by a switch which also provided a signal used to mark "time zero" on the data records. The delay introduced by the time constant of the valve was about 10 msec. and was neglected. Movements of the various prosthetic units were measured by coupling a precision potentiometer to the respective joint and displaying voltage changes on an oscillograph calibrated to give full span deflection for the total movement range. Figures 6, 7, 8, 9, 10, and 11 present recordings of deflection as a function of time for each component under the various load and pressure conditions described earlier. The following values have been determined from these records:

(a) Reaction time—Defined as the time required to obtain a deflection corresponding to 2 mm. of movement of the recording pen.

(b) Operation Time—Defined as the time required to obtain 80 percent of the total deflection of the available range of motion.

(c) Average Velocity—Defined as the ratio of 80 percent of full motion to operation time.

a. Reaction Time. Results of these tests are presented in Table 6. In general, time lags increased for powered movements as load was increased or as available pressure to the unit decreased. The reverse was true for passively operated antagonist movements except for the wrist unit.

b. Average Velocity. Results of these tests are presented in Tables 7, 8, and 9. Again increased load or decreased operating pressure enhanced passive movement velocities, but slowed active movements.

4. Trouble Points

a. Elbow Unit. Occasionally, the elbow locking mechanism would not disengage and permit flexion. This was found to be the result of jamming of the locking pin in its bushing. From excessive wear a small spur had developed on the front of the pin which jammed the locking pin on retraction.

b. Terminal Device. The finger pads became loose frequently during testing and had to be reglued. They also became quite worn and small pieces of the pads broke off at the edges.

c. Wrist Unit. No particular mechanical problems occurred during operation of the wrist mechanism.

d. Power Supply and Linkage. During normal operation the pneumatic lines became clogged at the nozzles of the control valve and prevented the operation of some functions of the arm. Although this was not particularly difficult to repair, it required a knowledge of the specific linkages to each function and the ability to remove and replace the connectors that secured the tubing to the valve nozzle. Such maintenance would be quite difficult for an amputee but would not be expected to occur frequently with a clean CO_2 supply.

Filling and changing of the portable CO_2 source was another trouble point. Closing and opening of the valve at the neck of the CO_2 bottle and removal and replacement of the screw-in regulator would be tedious with the use of only one hand without the aid of special holding devices. This criticism applies only to United States commercial devices which were used and with which other American users may have to contend.

During the engineering testing, the pneumatic lines broke frequently under pressure. Substitution of a polyethylene tubing should avoid this problem which was due to deterioration of the rubber tubing, possibly caused by atmospheric smog.

e. Control System. One of the ball-type pressure greasers used in the seven-position control valve became worn and sometimes jammed on release of the control cable. This problem became more frequent after the second

TABLE 6.—*Mechanical Time Lags of Prosthetic Movements, Loaded and Unloaded*

Loads	Gas pressure (p.s.i.)		
	45	55	65
	Flexion		
No Load:	192	176	168
0.62 lb.	200	184	172
1.25 lb.	228	220	188
2.00 lb.	312	280	260
	Extension		
No Load:	520	530	750
0.62 lb.	350	380	420
1.25 lb.	280	300	320
2.00 lb.	220	250	280
	Pronation		
No Load:	380	480	520
0.75 lb.	440	540	600
1.49 lb.	600	600	580
	Supination		
No Load:	820	608	512
0.75 lb.	1040	680	520
1.49 lb.	—[a]	768	660
	T.D. closing		
No Load	108	88	80
	T.D. opening		
No Load	360	460	580

NOTE.—All values are in milliseconds.
[a] No movement.

TABLE 7.—*Average Velocities of Elbow Unit, Loaded and Unloaded*

Load and pressure	Flexion			Extension		
	Operation time[a]	Deflection[b]	Velocity[c]	Operation	Deflection	Velocity
No Load:						
45[d]	772	65	84. 2	1480	67	45. 3
55	704	70	99. 4	1590	68	42. 8
65	344	72	209. 3	1700	70	41. 2
0.625 lb.:						
45	1120	62	55. 4	1500	67	44. 7
55	736	65	88. 3	1570	68	43. 3
65	588	68	115. 6	1780	71	39. 9
1.25 lb.:						
45	1352	57	42. 2	1320	58	43. 9
55	1180	60	50. 8	1400	64	45. 7
65	1112	64	57. 6	1580	68	43. 0
2.00 lb.:						
45	1128	37	32. 8	880	50	56. 8
55	1200	52	43. 3	1060	52	49. 1
65	1160	56	48. 3	1220	57	46. 7

[a] Values are in milliseconds.
[b] Values are in degrees.
[c] Values are in degrees per second.
[d] Values are in pounds per square inch.

month of testing. It was temporarily relieved by repeated pulling of the control chain until the position of the worn spot was moved from the area of contact with the cam.

C. Basic Control Characteristics

1. Control Valve Function

Operation of the arm is determined by two control valve units: (a) a wrist control valve, and (b) a terminal device and elbow control valve. The wrist control valve is a four-valve, four-position control. The action of these valves is as follows:

Valve 1: Inflates wrist lock chamber, pushing wrist locking rod into appropriate wrist locking hole, locking wrist.

Valve 2: Exhausts wrist lock chamber, allowing spring-loaded locking rod to retract, unlocking wrist.

Valve 3: Inflates wrist supination bellows, supinating wrist.

Valve 4: Exhausts wrist supination bellows, allowing spring-loaded bevel gear to pronate wrist.

The sequence of operations of the wrist control valve is shown in Table 10.

TABLE 8.—*Average Velocities of Wrist Unit, Loaded and Unloaded*

Load and pressure	Pronation			Supination		
	Operation time[a]	Deflection[b]	Velocity[c]	Operation time	Deflection	Velocity
No Load:						
45[d]	500	159	318.0	1930	158	81.9
55	480	159	331.3	1337	158	118.1
65	520	160	307.7	1058	160	151.2
0.75 lb.:						
45	328	159	484.8	3240	158	48.8
55	332	159	478.9	2040	158	77.5
65	340	159	467.6	1530	160	104.6
1.49 lb.:						
45	336	158	470.2	—[e]	—	—
55	346	158	456.6	6412	185	28.9
65	425	155	364.7	2620	185	71.4

[a] Values are in milliseconds.
[b] Values are in degrees.
[c] Values are in degrees per second.
[d] Values are in pounds per square inch.
[e] No movement.

TABLE 9.—*Average Velocities of Terminal Device*

Gas pressure (p.s.i.)	Closing			Opening		
	Operation time[a]	Deflection[b]	Velocity[c]	Operation time	Deflection	Velocity
45	404	34	84.2	680	34	50.0
55	332	35	105.4	780	34	43.6
65	280	35	125.0	700	35	48.6

[a] Values are in milliseconds.
[b] Values are in degrees.
[c] Values are in degrees per second.

TABLE 10.—*Flow Diagram for Four-Position Control Valve*

Step	Function	Valve 1	Valve 2	Valve 3	Valve 4
0	Rest				
1	Wrist Lock	•			
2	Release Wrist Lock		•		
3	Pronation		•		•
4	Supination		•	•	

NOTE.—Open valves are indicated by a dot.

The terminal device and elbow control unit is a six-valve, seven-position control. The action of these valves is as follows:

Valve 1: Inflates thumb adduction bellows, closing thumb.

Valve 2: Exhausts thumb adduction bellows, allowing spring to open thumb.

Valve 3: Inflates elbow lock bellows, pushing locking pin into gear of elbow mechanism, locking elbow.

Valve 4: Exhausts elbow lock bellows, allowing spring-loaded locking pin to retract, unlocking elbow.

Valve 5: Inflates elbow flexion bellows, flexing elbow.

Valve 6: Exhausts elbow flexion bellows, allowing extension of forearm by force of gravity.

The sequence of operations of the terminal device and elbow control valve is shown in Table 11.

TABLE 11.—*Flow Diagram for Seven-Position Control Valve*

Step	Function	Valve 1	Valve 2	Valve 3	Valve 4	Valve 5	Valve 6
0	Rest						
1	Thumb adduction	•					
2	Thumb abduction		•				
3	Thumb adduction	•					
4	Thumb adduction, elbow lock	•		•			
5	Release elbow lock				•		
6	Release elbow lock, extend				•		•
7	Flex elbow				•	•	

NOTE.—Open valves are indicated by a dot.

In Tables 10 and 11, a zero or rest position is noted for each valve. These are completely inactive settings to which the unit returns when the amputee relaxes tension in the control straps.

The particular sequence of valve operations and choice of functions for each valve has been carefully chosen by the designer. One example of an important design decision is the repetition of hand closing on both sides of the hand opening control position (see Table 11). This arrangement has three advantages: (1) if the valve is accidentally activated from the position of rest, hand closing is a less dangerous function to be activated than hand opening, especially when an object is being transported. (2) When returning to the position of rest, passing through the closing position (step 1) last (before rest) counteracts the slight opening that occurs during travel through the hand opening control position (step 2). (3) Having a second position for hand closing (step 3 as well as step 1) permits activation of hand closing directly after elbow activation without passing through the position for hand opening. With this arrangement, the chances of accidentally opening the hand and/or dropping an object are reduced.

Other decisions about the sequence of operations of each valve and the assignment of functions to the two controls units were made by the designer after careful observation of a number of different arrangements. The rationale for the final design has been described in detail by the designer (Marquardt and Haefner, 1957).

2. *Control Valve Displacements and Forces*

The displacement of the control chain required to advance the seven-position control valve through one step was about 0.15 in., except for step 4 which immediately followed step 3. The forces necessary to achieve these displacements ranged from a 3.5-lb. force required to advance to step 1 to a 6.0-lb. force required to advance to step 7.

The displacement of the control lever required to advance the four-position control valve through one step varied from 0.09 to 0.20 in. The forces necessary to achieve these displacements ranged from 0.9 lb. at step 1 to 2.0 lb. at step 4.

II. PERFORMANCE EVALUATION

A. Subjects

Two subjects were chosen to wear the experimental arm for performance testing. Table 12 describes the subjects. Subject 1 was a unilateral right standard above-elbow amputee, and Subject 2 a unilateral right forequarter amputee, both in good health. Subject 1 is a regular wearer of conventional prostheses and is quite proficient in their use. Unfortunately, it was not possible to obtain the services of a forequarter amputee who was also a regular wearer.

The subjects were chosen in order to represent the more severely handicapped amputee population, for whom prosthetic replacement of lost function by externally powered devices is of greatest importance. Figures 16, 17, 18, and 19 illustrate the degree of amputation of each subject.

Ideally, an evaluation should be based on a comparison of performance between an experimental and a conventional prosthesis as worn by the same amputee. Such a comparison was possible only for the standard above-elbow subject. Performance of the forequarter amputee was evaluated also in terms of data obtained from the above-elbow subject. It should be emphasized that such a cross-subject comparison of functional regain is not desirable but was dictated by necessity.

B. Prosthetic Systems

1. Prosthetic Fitting

All socket fabrications and fittings of the experimental arm were performed by Carl Sumida, C.P., of the Child Amputee Prosthetics Project, University of California at Los Angeles. The socket of the conventional arm worn for testing by the above-elbow amputee was fabricated by Woodrow Yamaka, C.P., of Alpha Orthopedic Appliances, Los Angeles, California. Mr. Yamaka has serviced this amputee periodically for several years.

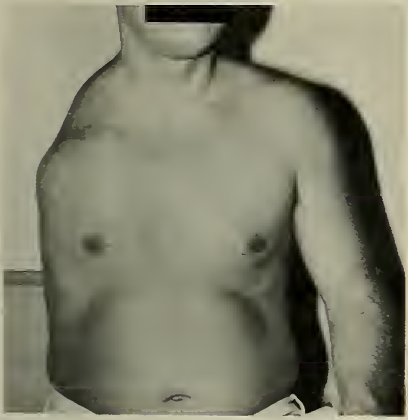


FIGURE 16. Forequarter amputee (front view).

Table 12.—*Description of Subjects*

Subject data	Subject No. 1	Subject No. 2
Sex	Male	Male
Age	47	26
Height	5′9½″	6′2″
Weight	180 lb.	180 lb.
Occupation	Draftsman, architectural field supervisor.	Student
General health	Good, with exception of heart attack 3 years ago which requires avoidance of strenuous activity.	Good
Attitude	Good	Good
Intelligence	Above average	Above average
Amputation	Unilateral right standard above-elbow.	Unilateral right forequarter.
Stump measurements	5½″ from acromion to end of stump.	None
Length of upper left arm	12″ from acromion to elbow center.	12½″ from acromion to elbow center.
Length of lower left arm	10½″ from elbow center to wrist.	11″ from elbow center to wrist.
Cause of amputation	Traumatic (industrial accident)	Surgical (malignant growth).
Age at amputation	21	23
Present prosthesis	Conventional Hosmer internal elbow, VO hook, figure 8 harness.	Has been fitted for a CO_2 powered Sierra.
Use of present prosthesis	Regular use during job and leisure activities.	None
Experience	Has worn prostheses since 1942; connected with prosthetic testing and training programs since 1950.	Inexperienced

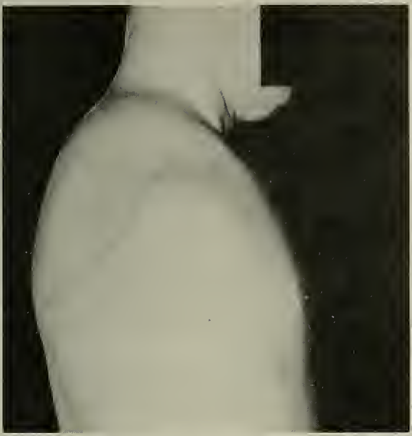


Figure 17. Forequarter amputee (side view).

Figure 18. Standard above-elbow amputee (front view).

2. *Conventional Prosthesis*

The prosthesis worn by the above-elbow subject consists of a conventional Hosmer internal elbow turntable, a Sierra Model B wrist flexion unit, and a Northrop-Sierra two-load, heavy-duty VO hook with specially canted fingers. The elbow unit is mounted in a standard above-elbow double-wall plastic laminated socket. A "figure 8" harness supports the prosthesis, with the standard dual control arrangement for elbow flexion, elbow locking, and terminal device opening. The prosthesis is shown in Figure 20. No changes were made to this prosthesis during testing besides minor readjustments in tightening the harness straps.

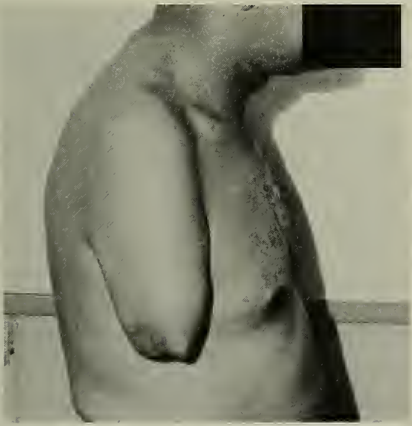


Figure 19. Standard above-elbow amputee (side view).

Figure 20. Standard above-elbow amputee with conventional prosthesis.

3. Experimental Prosthesis—Above-Elbow Amputee

The experimental arm described in Section 1 was attached to a lightweight, single-wall, standard above-elbow socket by means of a wingnut and washer at the elbow. Prosthesis support was provided by a modified "figure 8" harness with elastic cross-back strap. The chain of the seven-position control valve was incorporated into the harnessing control attachment strap at the position of connection to the Bowden control cable on the conventional arm. The four-position control valve was located on the inner side of the socket and was covered by a large plastic flap. This prosthesis is shown in Figures 21 and 22. The amputee operated the seven-position valve by the same humeral flexion used in the conventional prosthesis to control elbow flexion and terminal device opening. He operated the four-position valve by humeral adduction, creating pressure against the flap covering the valve lever.

The wingnut at the elbow allowed manual adjustment of the angle of inward rotation of the elbow in a similar fashion to that obtainable in a conventional prosthesis with elbow turntable.

Two modifications were made to this prosthesis during the initial training period. First, a cross-back strap was added to the "figure 8" harness to improve stability of the fitting. Second, the location of the four-position valve was moved from under the frontal harness support strap to its present location (see Fig. 21). This was done to improve separation of control motions of the two valves, since in the initial location the subject was not able to achieve independent control of each valve. No further changes were made during testing.

4. Experimental Prosthesis—Forequarter Amputee

The experimental arm was attached to a conventional forequarter single-wall plastic laminated socket by the wingnut and washer arrangement de-

Figure 21. Standard above-elbow amputee with pneumatic arm (front view).

Figure 22. Standard above-elbow amputee with pneumatic arm (rear view).

scribed previously. A turntable at the shoulder of the socket permitted manual adjustment of the angle of humeral flexion. The wingnut arrangement permitted manual adjustment of the degree of inward cant of the forearm at the elbow.

The seven-position control valve was attached to the rear of the socket and was connected to a strap passing around the body to the front of the socket. Chest expansion against this strap was used to pull the chain of the control valve. The four-position control valve was mounted on a plastic sheet attached to the bottom of the socket on a line with the shoulder. An abdominal strap passed over the lever of this valve. Expansion of the stomach against this strap was used to depress this lever. Figures 23 and 24 illustrate these control arrangements. No changes were made to this configuration during testing.

C. Training

Training in the use of the experimental arm was conducted in two phases. In the first phase, the amputee practiced simple motions under the supervision of laboratory personnel. Each amputee was trained for about 16 hours in weekly sessions of two to four hours over a five-week period. This training consisted of initial familiarization with controls, then of simple drills for the separate functions of the arm, and finally of complex activities such as grasp and transport of a number of objects of different geometric shapes.

At this time, evaluation measurements for isolated movements were recorded. The amputees were sufficiently proficient to operate the arm in complex activities, but required additional practice for consistent performance. Therefore, training continued in its second phase during the period of testing of isolated motion. At the beginning of a day's testing,

FIGURE 23. Forequarter amputee with pneumatic arm (side view).

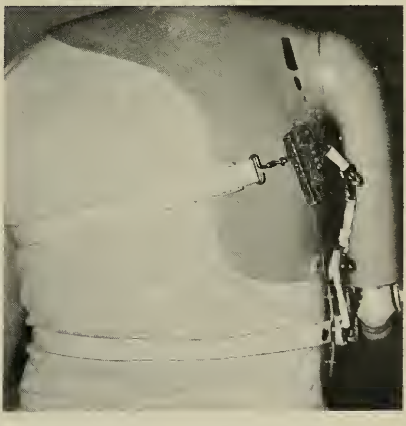


FIGURE 24. Forequarter amputee with pneumatic arm (rear view).

the amputee was allowed a warmup period of 15–30 min. in which he practiced various complex actions.

At the time evaluation measurements of performance tests of coordinated activity were initiated, the daily warmup period was reduced to about 10 min. and toward the end of the investigation to about 5 min.

In general, the forequarter amputee learned to operate the experimental arm at a faster rate than the above-elbow amputee. Three possible factors may have contributed to this difference:

(1) The forequarter amputee was much younger than the above-elbow amputee and better able to endure sustained training than the above-elbow amputee who had to avoid over-exertion because of a pre-existing heart condition.

(2) The control arrangement for the forequarter prosthesis was independent of the position of the articulated units of the arm, thus permitting a more positive and stable control operation.

(3) Since the above-elbow amputee was a very experienced wearer, he had more difficulty in mastering the control arrangement of the experimental arm due to conflict with habit patterns previously established with the conventional prosthesis.

Specific comments regarding progress in training for each amputee are as follows:

1. Above-Elbow Amputee

Separation of wrist and hand functions was not possible with the wrist control valve located under the frontal harness support strap. With this arrangement, inadvertent opening and closing of the terminal device occurred during operation of the wrist. For this reason the location of the wrist control valve was changed as described in Section I.B.2.b.

After 12 hours of training, the subject was able to operate the seven-position valve reliably, initiating the desired functions with few errors. Separation from wrist functions was good. However, he was not able to position the elbow accurately during flexion or extension, nor regulate closely the amount of terminal device opening. By the end of the formal training period, he was able to select the desired wrist movement easily, but could not control closely the amount of pronation movement. He also had particular difficulty in learning to position the open terminal device for a secure grasp.

2. Forequarter Amputee

After eight hours of training, this subject was able to separate the functions of the arm well. He experienced difficulty in controlling wrist pronation. When bending forward to grasp an object at table height, he frequently activated the wrist rotation valve, but by the end of the training period he had learned to avoid the abdominal expansion which was causing this problem. He experienced slight difficulty in learning to position the terminal device for grasp.

D. Performance Tests

1. *Range of Motion*

a. Objective. To measure the range over which the amputee can effectively operate the prosthesis.

b. Procedure. The amputee was instructed to position his prosthesis as if for use at each of the following positions:

(1) the mouth
(2) the breast pocket
(3) 90 deg. flexion of the elbow
(4) the entire arm perpendicular to chest
(5) the perineum
(6) the anus

The range of wrist motion and terminal device opening was measured at each position.

c. Apparatus. Terminal device opening was measured with a caliper between the centers of the finger pads of thumb and forefinger of the experimental arm and between the inner edges of the hook of the conventional arm. Wrist and elbow rotation angles were measured with clear plastic goniometers, attached directly to the prosthesis and aligned with the axis of rotation of the wrist and elbow.

d. Sensitivity. The caliper was graduated in increments of 0.025 in. All measurements of terminal device opening were repeated and showed little variation. Movements of the wrist and elbow were measured in degrees of rotation, taken visually by referring to a standard point on the forearm or humerus to the goniometer. These measurements were repeatable within one degree.

e. Results. Elbow flexion ranges were found to be the following:

(1) Above-elbow amputee—Conventional arm: 10 deg. to 135 deg. for a total of 125 deg.
(2) Both amputees—Experimental arm: 24 deg. to 118 deg. for a total of 94 deg.

All measurements were taken with the vertical plane as the zero reference point.

The terminal device openings and wrist rotation ranges obtained by the amputees at each standard elbow position are indicated in Table 13. These values are expressed as percentages of the maximum ranges that can be obtained from manual manipulation of the controls. These maximum ranges are the following:

(1) Terminal device—Conventional arm: 3.25 in.
(2) Terminal device—Experimental arm: 2.28 in.
(3) Wrist rotation—Experimental arm: 210 deg.

f. Comments. Terminal device opening for the experimental arm was measured while the terminal device opening valve was held open to avoid

TABLE 13.—*Percentage of Maximum Function Obtained with Each Prosthesis at Six Standard Elbow Positions*

Location	Standard AE conventional arm		Standard AE experimental arm		Forequarter experimental arm		Minimum terminal device opening recommended[a]
	Terminal device opening	Wrist rotation	Terminal device opening	Wrist rotation	Terminal device opening	Wrist rotation	
Mouth	75	....	100	100	100	100	50
Breast pocket	87	....	100	100	100	100	50
90° flexion	100	....	100	100	100	100	100
Perpendicular to chest	100	....	100	0	100	100	50
Perineum	100	....	100	100	100	100	50
Anus	48	....	0	0	100	100	50

Note.—All values are in percents.
[a] Santschi, 1958.

locking. This was necessary in order to achieve maximum opening, since an attempt to lock the terminal device when fully opened always resulted in a small amount of closure. This closure resulted from unavoidable travel through step 1 of the seven-position valve on return to the locked or resting position of the valve. For similar reasons wrist rotation range was measured with the four-position valve in active rather than locked positions. All measurements were made with a newly filled CO_2 cylinder to avoid reduction of the range due to reduced operating pressure.

Table 13 shows clearly that the amputees were unable to achieve intermediate control capabilities for the wrist and hand functions of the above-elbow experimental arm. Either the amputee was able to control these functions over their entire range at a particular elbow position or he was not able to operate them at all. For the conventional arm, terminal device range of motion was restricted when the arm was positioned at certain body areas. This resulted from a reduction in the amount of remaining travel in the control cable.

The forequarter amputee was able to achieve full wrist and terminal device operation with the experimental arm at all elbow positions tested. The standard above-elbow subject was not able to control the wrist at two test positions nor the terminal device at one of these. However, in the case of the wrist, this was simply a result of loss of contact between the wrist control valve lever and the side of the body when the arm was moved away from the body. For the terminal device, loss of function when the arm was positioned behind the back reflects a slackening of the harness control strap which actuates the seven-position valve. The results of the forequarter amputee make it clear that a control arrangement which is independent of the location of the prosthesis and harness would correct this loss of function.

The range of elbow flexion of the experimental arm is limited compared to that of the conventional arm, especially in regard to the upper limit of flexion. Besides being reduced to 75 percent of the range of the conventional arm, the experimental arm falls 17 deg. short of the 135 deg. upper limit attained with the conventional arm. The forequarter amputee was able to compensate partly for this lack by passive adjustment of the shoulder joint of his socket. This was not always a satisfactory solution since the forearm actually projected past the face and required turning and bending of the neck to reach the terminal device with the head. The standard above-elbow subject was able to reach his head only while bending his neck forward and with additional humeral stump flexion beyond that necessary to position the seven-position control valve in step 7 of the control. In addition, the standard above-elbow amputee was not able to operate the terminal device in close proximity to the head because this required sufficient relaxation of humeral stump flexion to allow the seven-position valve to fall from the

flexion control position to the terminal device control positions, thereby allowing the arm to move down from the face. Again, a control system arrangement independent of the position of the prosthesis would correct this loss of function.

In summary, the experimental arm was superior to the conventional arm in terms of range of wrist and terminal device function. Control valve operation was not restricted by arm position, assuming independence of control linkage, as was control cable travel in the conventional arm. The wide range of active wrist rotation provided more flexibility than did the passive wrist cant feature (3 settings) of the conventional arm. Also, the ability to manipulate elbow and wrist with the terminal device locked in any position of its range of opening was an improvement over the VO hook which returns to its initial state when the elbow is unlocked. Although the terminal device of the experimental arm has only three-fourths the range of opening of the conventional hook (2.3 in. versus 3.1 in.), this did not prove to be as limiting as the reduction in elbow range.

2. *Speed Tests*

a. *Objective.* To obtain a measure of the speed with which an amputee can initiate the motion of each of the functions of his prosthesis.

b. *Procedure.* All testing was done with the amputee standing in front of a visual display giving the necessary command words, as for example "flex," "extend," etc. The experimenter was able to illuminate any one of these commands by the operation of a switch which was concealed from the amputee. The amputee was instructed to watch the visual display and to perform the indicated command with his prosthesis as soon as possible after it was illuminated. Reaction time was measured simply as the difference in time between onset of illumination of the command word and initiation of the desired prosthetic movement.

Two types of reaction time scores were derived, *simple* and *complex*. In the simple situation the amputee was told which command would be presented before the trial began. In the complex situation he was given no advance information as to which command word would be presented. Twenty simple reaction time trials were presented for each function of each arm. Twenty complex trials were also presented, with the order of presentation varied according to a random schedule. Before each trial the amputee was given the verbal preparatory signal "ready," with a foreperiod that ranged from 1.0 to 2.0 seconds.

Errors or improper selections of function were recorded as a second performance measure on complex RT trials.

With the experimental arm, the amputee started each trial with the prosthesis locked at the center of the range of movement of each function. This method permitted movement of any component of the prosthesis in either direction to occur and be recorded on every trial. With the conventional

arm, the elbow was held at 90 deg., unlocked with the hook closed. All six movements of the experimental arm (flexion, extension, pronation, supination, opening, closing) were tested; three movements of the conventional arm (flexion, extension, opening) were tested.

Occasional "blank" trials on which no signal light was presented, although the subject was given a preparatory signal, were inserted into the testing schedule to discourage the subject from anticipating the command light. Anticipation was not a problem, apparently, since neither subject responded in the absence of the actual command light.

c. Apparatus. Movement around each joint of the prosthesis under test was monitored by attachment of rotary precision potentiometers to each joint (see Section II.D.3.c.). Each potentiometer was part of a circuit that provided a voltage analog to degrees or inches of movement around the joint. Movements and command presentations were recorded on four channels of an eight-channel oscillograph (Offner, Type R).

d. Sensitivity. Reaction time scores were computed from the speed of recording paper travel (25 mm./sec.). Data records were read to the nearest 0.25 mm. or 0.01 sec. Slight corrections were necessary for pen misalignment between recording channels.

e. Results. Both simple and complex reaction times for each prosthetic function are presented in Figure 25 for each amputee-prosthesis combination. These data are summarized respectively in Tables 14 and 15. Table 16 presents the errors (initiation of wrong movement) that occurred on complex reaction time trials with the experimental arm averaged over both amputees. Errors are classified by type for each prosthetic movement tested. Note that in some cases, the percentage of errors summed horizontally across the table is greater than 100 percent. This is due to the occurrence of more than one error on some trials.

TABLE 14.—*Simple Reaction Time Means and Standard Deviations*

Movement	Standard AE conventional arm	Standard AE experimental arm	Forequarter experimental arm
Flexion	0.31±0.03	1.19±0.16	0.57±0.29
Extension	0.36±0.05	1.03±0.19	0.71±0.19
TD Opening	0.63±0.07	1.37±0.22	0.60±0.23
TD Closing	....	1.00±0.19	0.37±0.13
Pronation	....	0.97±0.33	0.49±0.10
Supination	....	0.96±0.28	0.58±0.10

NOTE.—All values are in seconds.

TABLE 15. *Complex Reaction Time Means and Standard Deviations*

Movement	Standard AE conventional arm	Standard AE experimental arm	Forequarter experimental arm
Flexion	0.64±0.14	1.29±0.27	1.16±0.26
Extension	0.64±0.12	1.74±0.18	1.97±0.13
Opening	0.86±0.12	1.98±0.46	1.48±0.19
Closing	....	1.39±0.40	1.21±0.23
Pronation	....	1.19±0.23	1.08±0.17
Supination	....	1.52±0.33	1.84±0.24

NOTE.—All values are in seconds.

f. Comments. Simple reaction time scores were found to be lowest for the above-elbow subject with the conventional arm. Scores for the forequarter amputee on some items were almost as low. Reaction times for the above-elbow subject with the experimental arm were nearly twice as slow as his own peformance with the conventional arm.

Average complex reaction time scores were about equal for the two subjects with the experimental arm and were a 100 percent increase over those of the above-elbow subject with the conventional prosthesis.

The slightly longer reaction times found for terminal device opening with the conventional arm reflect that this was a two-step process requiring locking of the elbow before opening of the hook. The elbow was unlocked in both simple and complex reaction time trials at the start of each trial.

With the experimental arm, complex reaction times showed about the same relative pattern for the six movements of the prosthesis for both subjects. Extension, opening, and supination were all slower to be initiated than flexion, closing, and pronation. In view of the similarity of complex reaction times found with this prosthesis for both subjects, it is hard to explain the large difference found between them in simple reaction time scores, both in terms of absolute values and in terms of relative distribution over the various prosthetic movements.

Since complex reaction time scores showed good agreement for both subjects with the experimental arm, they probably reflect better the ability to initiate prosthetic movement than does the simple reaction time situation. There is no question that the standard above-elbow subject is much faster to initiate movement with the conventional arm than either subject with the experimental arm. In part, the difference found (about 0.70 seconds) reflects the difference in the number of choice alternatives with the two prostheses, six movements for the experimental versus three for the conventional. However, this value cannot be completely accounted for by the increased task complexity since the increased number of alternatives would only be expected to add 200 to 300 msec. to the complex reaction time scores (Woodworth & Schlosberg, 1954).

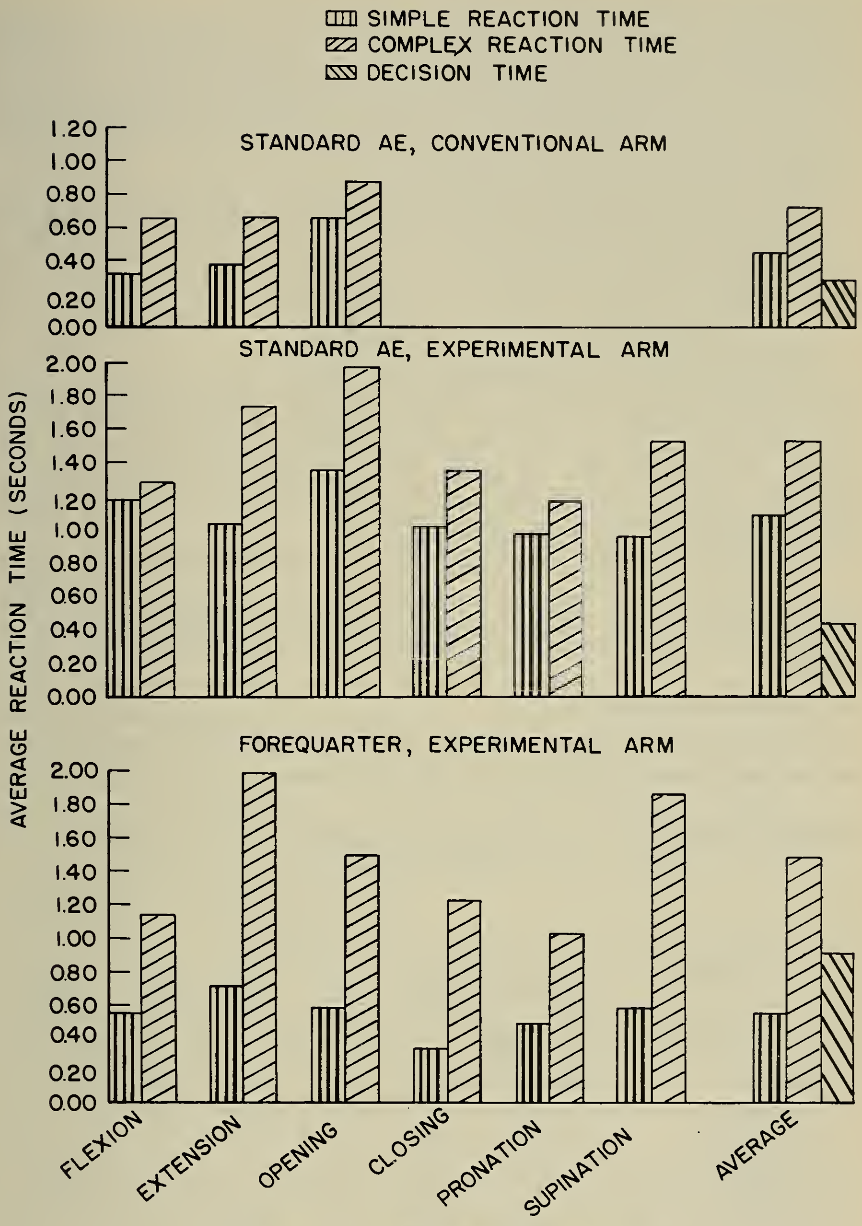


FIGURE 25. Average reaction time scores.

An analysis of the errors on the complex reaction time trials with the experimental arm showed that only eight specific error types occurred for both amputees. These are reported in Table 16. Four of these errors, three closing errors and one pronation error, occurred with very high probability

on trials of the particular function under test. In most cases they were not errors in the true sense. Rather, they reflect the fact that for each control valve there was one position (step 1 on the seven-position valve, and step 3 on the four-position valve) for which it was almost impossible to avoid some unwanted movement during travel through these positions to reach positions farther along the control sequence.

Four error types represent a true confusion in the selection of prosthetic function. These are the following:

(1) Extension instead of flexion (27.5 percent)
(2) Flexion instead of extension (12.5 percent)
(3) Pronation instead of closing (10.0 percent)
(4) Closing instead of supination (32.5 percent)

The first two errors represent confusion between control positions on the same valve while the last two represent activation of the wrong valve entirely. Comparison with errors made with the conventional arm (10 percent extension errors on flexion trials and 20 percent flexion errors on extension trials) shows that these errors are not excessive.

In summary, although error rates between conventional and experimental arms were similar, initiation of movement with the experimental arm was twice as slow as with the conventional arm in the complex reaction time situation.

3. *Precision of Motion*

a. Objective. To obtain a measure of the precision with which an amputee can operate each of the functions of his prosthesis.

TABLE 16.—*Percentage of Errors (Initiation of Wrong Movement) Occurring on Complex Reaction Time Trials*

Movement	Type of Error					
	Flexion	Extension	TD opening	TD closing	Pronation	Supination
Flexion	——	[a] 27. 5	2. 5	[a] 92. 5	2. 5	0
Extension	[a] 12. 5	——	0	[a] 95. 0	0	0
TD Opening	0	0	——	[a] 85. 0	2. 5	0
TD Closing	0	0	2. 5	——	[a] 10. 0	0
Pronation	0	2. 5	0	2. 5	——	0
Supination	2. 5	5. 0	0	[a] 32. 5	[a] 85. 0	——

[a] Denotes error made by both amputees.

b. Procedure. Three functions were tested for the experimental arm (elbow, wrist, and terminal device movement) and two functions for the conventional prosthesis (elbow and terminal device movement). The

amputee was instructed to lock his prosthesis at one of the two extreme positions of the function to be tested. Upon command, the amputee attempted to position and lock the arm at a position indicated by a visual pointer that was adjustable along the plane of movement of the function being tested. After completing a trial, the subject returned his prosthesis to the starting position and the visual indicator was also returned to its zero position before being reset for the next test position. The subject was instructed to work at a normal pace and to match the test position as accurately as possible. Five minute rest periods were taken after every five or ten trials.

For the elbow, five test positions in its range of motion were chosen. Four of these positions, the same for conventional and experimental arms, corresponded to locking positions of the experimental arm; the fifth represented a point close to the upper limit of flexion. Similarly, five test positions in the range of wrist rotation were chosen; these also were locking positions. For the terminal device which has no specific locking positions along its range of motion in either prosthesis, four widths of opening were chosen.

A series of 40 trials was performed at each test position of each prosthetic function. Twenty of these trials were performed with the prosthetic component starting at one end of its range of motion and 20 were done with it starting from the other end. Testing of terminal device opening with the conventional prosthesis was the only exception. Since the hook used does not lock open, only 20 trials were performed at each test position with this component, all starting from the completely closed position. The order of presentation of these test positions was randomized for each prosthetic function tested. All testing was completed on one function before beginning the next.

c. Apparatus. The clear plastic goniometers used to measure range of motion were employed in these tests to indicate to the amputee the test positions to be matched. These goniometers acted as visual indicators for elbow and wrist rotation. For terminal device opening, a simple device consisting of two large metal pins mounted on a metal base was used. The distance between the pins could be adjusted manually to indicate the desired amount of terminal device opening.

Movement around each of the three joints of the experimental arm (and the two joints of the conventional arm) was monitored by attachment of a precision potentiometer to the particular joint and members in question. The potentiometer was part of a circuit that provided a voltage analog to degrees or inches of movement. In this manner, every movement around a joint could be sensed and recorded as it occurred in time. A two-channel inkwriting oscillograph (Offner, Type RS) was used to record the voltage across the potentiometers.

Visual inspection of data records permitted measurement of several criterion scores for each trial. Among these were:

(1) time to completion

(2) number of extra movements

(3) size of each extra movement in degrees or inches

d. Sensitivity. The recording system was calibrated before testing began on each function using a goniometer or a caliper to compare the actual physical position or the prosthetic component to its position as displayed on the oscillogram. Calibration procedures were repeated midway during testing and again at the end of testing. Spot checks were made at every rest period. A correction table for nonlinearity in the recording system was developed from each calibration and used in data reduction.

Time scores were computed from speed of recording paper travel. They were accurate to about 0.1 seconds. Degrees of rotation or inches of movement were read to the nearest 0.25 mm. with an accuracy of about 0.25 mm. (±1 degree of rotation or ±0.05 in.). The number of excess movements or readjustments was derived simply by counting each discrete rise or fall in voltage in a data record.

e. Results. The results of precision of motion tests for each function of the experimental and conventional prostheses are presented graphically in Figure 26. These data are summarized in Table 17. In these graphs, a separate curve is presented for each arm-amputee combination. The

TABLE 17.—*Precision of Motion Test Means and Standard Deviations*

Test position	Standard AE conventional arm	Standard AE experimental arm	Forequarter experimental arm
Elbow:			
39°	1.9±1.2	16.5±16.8	10.1± 6.4
75°	2.7±1.5	16.7±10.0	13.9± 6.0
93°	2.1±1.0	6.8± 4.2	7.4± 4.4
111°	2.1±1.1	7.5± 5.8	3.5± 2.2
117°	2.1±0.6	....	4.8± 1.3
Wrist:			
81°P	....	26.4±26.7	13.0±15.9
47°P	....	13.4±15.3	3.5± 2.1
0°	....	22.7±24.1	6.2± 4.9
48°S	....	13.4±11.0	2.8± 1.3
84°S	....	6.3± 3.6	3.1± 1.4
Terminal Device:			
0.3 in.	4.0±6.6	8.9± 7.8	7.5± 8.7
0.8 in.	5.3±7.4	11.4± 6.2	10.2±10.1
1.4 in.	4.9±5.6	14.7± 5.3	11.2± 9.0
2.2 in.	3.3±2.9	17.0±18.1	6.1± 7.2

NOTE. All values are in seconds.

dependent variable is the total time taken to reach the desired test position and it is graphed as a function of the test position to be assumed. Test positions for each prosthetic function are spaced along the abscissa of each graph so that they correspond to the actual spatial separation of test positions along a linear scale.

Most data points represent the average of 40 trials as earlier noted, combining trials from both initial starting positions for each test position of each function.

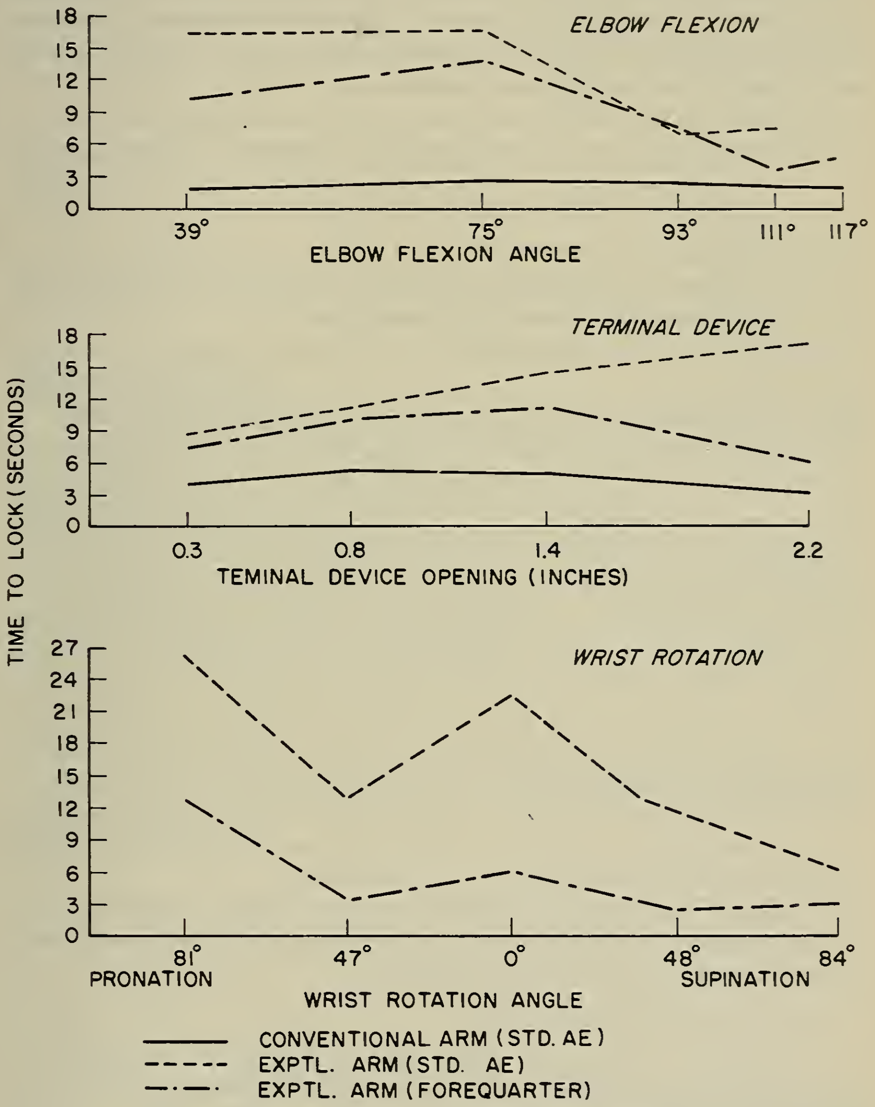


Figure 26. Precision of motion for experimental and conventional prostheses.

f. Comments. Although data were gathered for other dependent variables in addition to time taken to reach test position, these data will not be presented in any detail. It should be noted that the number of readjustments taken was found to parallel time scores closely for each function. To obtain a rough approximation of the average number of readjustments taken to reach a test position with the experimental arm, it is only necessary to multiply the time score in seconds by a factor of either 1.0, 0.5, or 0.33 for wrist, elbow, and terminal device, respectively.

For both wrist and elbow movements of the experimental arm, no final error measure was possible since fixed locking positions were chosen for testing these functions. Results for the terminal devices were good, with final error within ±0.1 in. with both prostheses.

The following two facts are evident upon inspection of Figure 26:

(1) On all functions for which a comparison between the two prostheses is possible, precision of motion is far superior with the conventional arm.

(2) Precision of motion scores are relatively flat over the range of motion of each function with the conventional arm, while this is never the case with the experimental arm.

Performance with the experimental arm is somewhat better for the forequarter amputee than for the above-elbow amputee. However, their curves follow the same pattern over the range of test positions of each function.

Originally, it was planned to treat precision of motion data separately for each function with respect to the starting position of the prosthesis, or the initial direction of movement. For example, data for wrist rotation trials starting from full supination of the wrist would have been presented separately from the data for those trials on which the amputee started from a fully pronated position. The hypothesis was that as the distance of the test position increased from the starting position of the prosthetic component, accuracy would increase because the amputee would have more time in which to release the control valve and lock the prosthesis. However, since such a large number of readjustments occurred on most trials with the experimental arm, starting position could not have had any practical significance. Inspection of the data in regard to initial starting position revealed no such relationship, and data for each function are thus presented only as a function of test position, regardless of starting position.

In summary, the practical ability of being able to position rapidly and hold any component in a specific position accurately was found to be quite poor for both amputees using the experimental arm.

4. Analysis of Coordinated Motion

a. Objective. To assess the adequacy of the prosthesis as an integrated, articulated unit capable of performing complex tasks, and to assess the degree of independence an amputee can achieve with it on everyday tasks.

b. Procedure. Fifteen simple tasks were chosen as representatives of the more difficult activities an amputee might perform in daily life. Each amputee performed these tasks under the observation of laboratory personnel. In order to obtain an objective rating of his performance, time and error scores were recorded by the observer for each perfomance trial. Subjective estimates of performance were also recorded as supplemental data.

Specifically, the amputee, wearing the particular prosthesis to be tested, was instructed in the method of task performance. He then practiced the task until in the judgment of the observer and the amputee he had reached a fairly stable level of performance. The amputee then began a series of 50 trials on the task. Total completion time and number of errors (regrasping, excess motions, dropping of objects) were recorded for every trial as well as any incidental observations. Five minute rest periods were taken after every five or ten trials (depending on task difficulty) or sooner if requested by the amputee.

If at any time during testing the amputee was able to complete five successive trials within a range of 0.5 seconds (for trials requiring less than 15 seconds to complete) or within 1.0 seconds (for tasks over 15 seconds in duration), testing was stopped for that task. Although the amputee was aware of this time criterion, he was instructed that good performance rather than speed per se was desired.

Timing began at the instant the amputee was told to begin the task and was stopped when he had returned the prosthesis to the initial position after completing the task. All trials began and ended with the amputee at one of two standard starting positions, one standing and one sitting.

After the series of performance trials on each task, the amputee was asked to indicate his rating of the task as performed by him with the prosthesis on a 10-point scale which ranged from "excellent" to "unacceptable—physical damage." This scale is presented in Table 18.

The tasks as performed are listed below with task elements indicated sequentially.

Standing Start Position

Stand erect with arms relaxed at sides, feet positioned 45 deg. apart, terminal device closed.

Sitting Start Position

Sit erect, arms against the body, elbows level with the table and forearms resting on table edge at about the middle of the forearm, terminal device closed.

Standard Tasks

(1) Sharpening Pencil (Pencil I)

Standing start position—grasp wooden pencil lying flat on table in terminal device—insert pencil into sharpener—turn sharpener handle three times with

sound hand—remove pencil from sharpener—return to table top and release—return to start.

(2) Pencil to Pocket (Pencil II)

Standing start position—grasp pencil on table top with terminal device—transport pencil to opposite side breast pocket—insert pencil in pocket and release—return to start.

(3) Drinking Soup

Sitting start position—grasp spoon from table with sound hand—insert spoon in terminal device—dip spoonful of soup with terminal device—raise spoon to mouth and drink—return spoon to table top and release—return to start.

(4) Coffee Cup Drinking

Sitting start position—cup two-thirds full—grasp cup handle with terminal

Table 18.—*Amputee Task Rating Scale*

Subject Name ________________________________

Prosthesis ______________ Date ________ Task ________ Experimenter ________

Operational condition	Adjective rating	Description	Numerical rating
Normal operation	Satisfactory	Excellent	1
		Good	2
		Satisfactory with mildly unpleasant characteristics	3
Emergency operation	Unsatisfactory	Acceptable with unpleasant characteristics	4
		Unacceptable for normal operation	5
		Acceptable for emergency performance only	6
No operation	Unacceptable	Unacceptable even for emergency use	7
		Unacceptable—dangerous	8
		Unacceptable—uncontrollable	9
	Catastrophic	Unacceptable—physical damage	10

device—raise cup to mouth and drink—return cup to table and release—return to start.

(5) Water Glass Drinking

Sitting start position—glass two-thirds full—grasp glass in terminal device—raise glass to mouth and drink—return glass to table and release—return to start.

(6) Hanger Task

Standing start position—grasp wooden hanger on table top in terminal device—raise hanger from table top and transport 10 feet to clothes tree—hang hanger on clothes tree and release—return to start.

(7) Briefcase Transport

Standing start position—bend body down and grasp handle of briefcase which is sitting upright on floor—straighten up body and walk 10 feet to table, raising briefcase to table top height—lift briefcase onto table and release—return to start.

(8) Answer Telephone

Sitting start position—grasp phone receiver in sound hand—place receiver in terminal device—raise receiver to ear, holding for five seconds while writing with sound hand—release receiver at ear into sound hand—replace receiver on cradle with sound hand while returning prosthesis to start position.

(9) Open and Close Door

Standing start position—grasp knob of door in terminal device—rotate knob until unlocked—pull door open to 90 deg. and release—close door with strong push from prosthesis—return to start.

(10) Remove and Replace Jar Lid

Standing start position—grasp jar lid in terminal device and lift jar from table top—rotate jar in sound hand to unscrew from lid—rotate jar back into lid to tighten—replace jar on table with terminal device and release—return to start.

(11) Zip and Unzip Trouser Fly

Standing start position—use sound hand to position zipper tab for grasp—grasp tab with terminal device—pull tab down with prosthesis to unzip—pull tab up with prosthesis and release—flatten tab with sound hand—return to start.

(12) Grasp and Light Cigarette

Standing start position—grasp cigarette in opposite side breast pocket with terminal device—raise cigarette to mouth and insert—release cigarette and extend prosthesis to about 90 deg. flexion—place matchbook in terminal device with sound hand—simulate striking of match with sound hand—return to start.

(13) Remove and Replace Bill in Wallet

Standing start position—remove wallet from pocket with sound hand—

hold wallet open with sound hand—grasp and remove bill from wallet with terminal device—place bill on table and release—grasp different bill on table with terminal device—insert bill in wallet and release—replace wallet in pocket with sound hand—return to start.

(14) Signature Task

The purpose of this task was to determine whether the amputee could write his name legibly using the prosthesis. No time or error scores were taken since quality of performance was the only concern. The amputee merely wrote his name 50 times with pencil and paper while seated at a table.

(15) Table Setting

The amputee was required to prepare a standard table setting using a plate, a bowl, a cup and saucer, and four pieces of silverware. The items were located in the center of a table, two feet from the edge. The amputee bent forward and grasped each item separately, placing it at the proper place in the marked outline of a place setting at the table edge. The instructions for this task emphasized speed more than quality of performance. The purpose was to obtain a measure of performance with the prosthesis under stressing circumstances. Time and error scores were taken for each of 25 trials on this task, with rest periods after every five trials. Only one practice trial was allowed before testing began.

c. Apparatus. The equipment used in the standard sequence tasks is given in the task descriptions. A stopwatch graduated in tenths of a second was used for time measurements. Errors were counted visually by the observer and recorded with the time scores immediately after each trial.

Testing was done in a closed, well-lighted laboratory room. Both amputees used identical equipment for all tasks including the table and an adjustable stool (for seated tasks).

d. Sensitivity. Stopwatch readings were recorded to the nearest tenth of a second. A slight systematic error may have been introduced by differences in method of timing between observers and in the difference between reaction times of each observer; however, every effort was made to standardize these measurements.

Since evaluation of the severity of an error is complex and at best arbitrary, it was decided to count any discrete movement in excess of those necessary to complete the task as an error. Thus regrasps, dropped objects, interrupted motions and the like were weighted equally and tallied as one error for each occurrence. In general, the same observer graded the performance of one amputee over the entire series of 50 trials on a task. In a few cases, where testing was conducted for more than one day, a different observer was used on the second day. Inspection of these data showed no significant difference in error or time scores between observers, indicating good agreement in individual criteria.

e. Results. Overall performance on the first 13 standard tasks described

in Section II.D.4.b. for each amputee-prosthesis system is illustrated in Figure 27. The six curves illustrate both average errors and average completion times on these tasks for 10 trial blocks over the 50 trials. It should be noted that not all data points represent an average based on 130 individual scores (13 tasks X 10 trials/task) since some tasks were halted before 50 trials if the amputee reached the criterion for stable performance.

Table 19 presents a breakdown of results for each of the thirteen standard tasks as performed by each amputee-arm system. Included in this table are the following values:

(a) Best performance time—expressed either as criterion time for trials halted before 50th trial or as the average of the last five errorless trials.

(b) Total errors made during testing on each task.

(c) Total trials completed for each task.

(d) Average errors per trial for each task.

(e) Whether or not amputee reached time criterion on the task.

(f) The amputee's rating of his performance on the task.

Time and error scores for the table set tasks are presented in Figure 29. These curves represent performance by each amputee-arm system averaged over successive blocks of five trials.

On the signature task both amputees were able to produce a legible signature after some practice. The standard above-elbow subject performed better with the conventional arm than with the experimental arm, but after 50 trials he had improved the quality of his signature to nearly the same level with the latter prosthesis. The forequarter amputee was only able to produce a signature of fair quality after 50 trials.

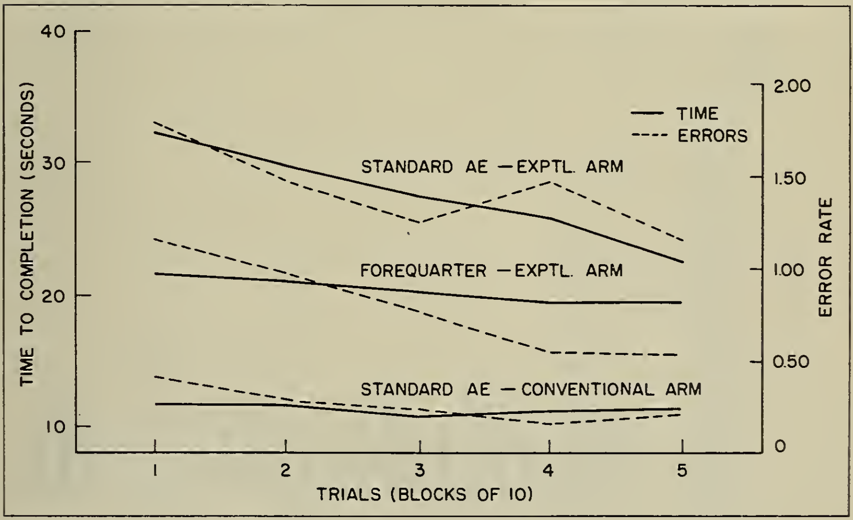


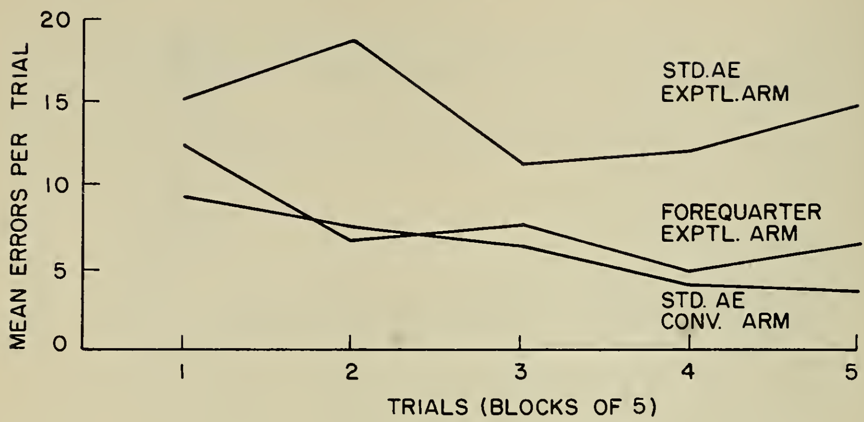
FIGURE 27. Performance on 13 standard tasks.

TABLE 19.—*Summary of Performance on Standard Tasks*

Task	Best time (sec.)	Total errors	Total trials	Average error	Was criterion reached?	Amputee rating of task[a]
Standard AE conventional arm:						
Pencil I	9.8	0	22	0.00	yes	2
Pencil II	6.1	12	50	0.24	no	2
Soup	8.5	5	28	0.18	yes	2
Coffee Cup	15.1	16	50	0.32	no	6
Glass	12.0	16	50	0.32	no	5
Hanger	5.5	5	32	0.16	yes	2
Briefcase	6.2	18	50	0.36	no	2
Telephone	15.7	16	50	0.32	no	2
Door	8.0	3	45	0.07	no	5
Jar	17.5	29	50	0.58	no	5
Zipper	9.1	20	34	0.59	no	5
Cigarette	10.5	9	29	0.31	yes	6
Billfold	13.1	9	50	0.18	no	3
Standard AE experimental arm:						
Peneil I	12.8	49	50	0.98	no	2
Peneil II	14.9	79	50	1.58	no	3
Soup	22.9	106	50	2.12	no	4
Coffee Cup	17.7	38	50	0.76	no	6
Glass	22.5	23	21	1.10	yes	2

Hanger	14. 5	23	50	0. 46	no	2
Briefcase	17. 1	35	50	0. 70	no	3
Telephone	21. 9	37	50	0. 74	no	2
Door	25. 0	52	50	1. 04	no	3
Jar	20. 3	40	50	0. 80	no	7
Zipper	25. 4	128	50	2. 56	no	9
Cigarette	19. 3	153	50	3. 06	no	6
Billfold	32. 6	123	50	2. 46	no	2
Forequarter experimental arm:						
Pencil I	15. 5	21	19	1. 11	yes	1
Pencil II	12. 1	21	37	0. 57	yes	2
Soup	13. 0	18	50	0. 36	no	8
Coffee Cup	19. 8	41	50	0. 82	no	10
Glass	28. 8	36	50	0. 72	no	6
Hanger	13. 6	47	50	0. 94	no	1
Briefcase	18. 2	43	50	0. 86	no	3
Telephone	24. 5	17	18	0. 94	yes	2
Door	16. 5	26	50	0. 52	no	3
Jar	18. 0	25	50	0. 50	no	4
Zipper [b]	....	....	....	....	....	....
Cigarette	16. 4	96	50	1. 92	no	4
Billfold	17. 3	41	50	0. 82	no	1

[a] See Table 18 for explanation of rating values.
[b] Subject was unable to complete task.



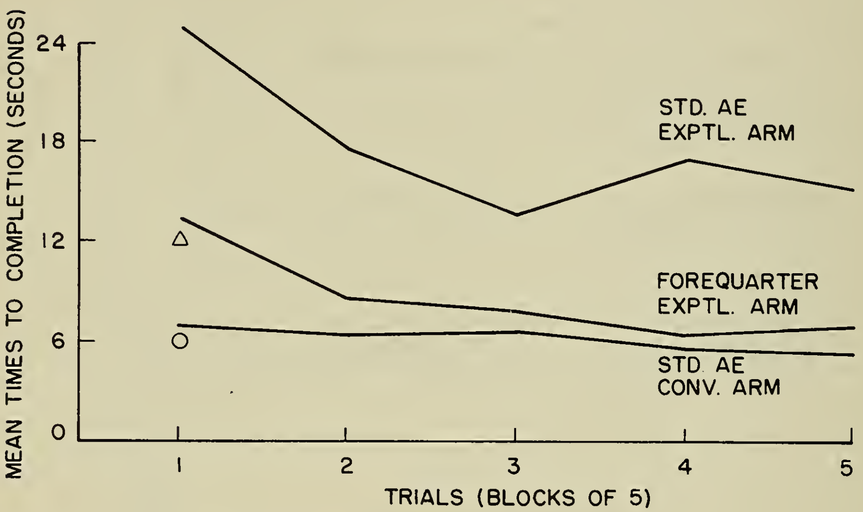


FIGURE 28. Performance on table set task.

△ 1st trial average of above-elbow amputees, VO hook (from Groth and Lyman, 1957).

○ 1st trial average of 5 above-elbow amputees, VO hook, adjusted for difference in number of task objects.

f. Comments. The order of testing for each amputee progressed from the simpler standard sequence tasks to the more complex. Depending on the initial reaction of the amputee to a task and his success with it in the pre-test training period, some tasks were not performed in order but were deferred until later testing. For this reason, and also because these tasks cannot be equated in terms of difficulty, it is not meaningful to display performance data here as a function of task test order.

Performance on the 13 standard sequence tasks by the standard above-elbow subject using the conventional prosthesis was good throughout testing both in terms of average errors and average completion times. Since this subject was quite proficient in the use of this prosthesis, little learning would be expected. Slight evidence of learning is given by the small reduction in error scores which occurred for him. No change was observed in average time taken for task completion.

With the experimental arm, both subjects were considerably slower and committed more errors, the forequarter amputee showing a better overall level of performance. The standard above-elbow subject improved both in time and error scores while the forequarter amputee improved only in error scores.

Performance on the table setting task presented a somewhat similar picture. In this task, in which no practice was allowed and in which subject instructions emphasized speed of performance, the same rank order of proficiency of arm-amputee systems resulted as for the 13 standard tasks. Again the performance of the above-elbow amputee with the conventional prosthesis was much better than with the experimental arm. Performance by the forequarter amputee with the experimental arm was intermediate between the two, but was much closer to the level of the standard above-elbow with the conventional arm than it was for the 13 standard tasks.

In general, error scores on the table-setting task were greater than on the 13 standard tasks, while time scores were superior. This would be expected considering the nature of the tasks and instructions. Also, more evidence of learning was found on the table-setting task, undoubtedly because pre-test practice was limited.

Scores with the conventional arm on the table-setting task are comparable to those obtained in another study (Groth & Lyman, 1957) using five unilateral above-elbow amputees with a VO hook. The average of their scores (one trial per subject) is higher than that obtained here for the standard above-elbow subject on the first five trials. When their scores are corrected for the difference in number of task objects involved, however (11 rather than 8), their times agree well with those obtained here (Fig. 28).

It is apparent that on the tasks described, performance with the experimental arm on the average is inferior to the conventional arm in terms of time and error scores. It is difficult to generalize regarding the superiority of one prosthesis over the other because of the difficulties of intra-individual comparison noted earlier (Section II.C.), and because of the difference in effective training periods for the two prostheses. The above-elbow amputee has been wearing the conventional prosthesis daily for over ten years. Total effective training on the experimental arm, including pre-task practice period and use during testing, is only of the order of 75 to 100 hours for each amputee. Nevertheless, considering the level of skill represented by these training periods, any further improvement in the use of the experimental

arm would be expected only after much additional training and use of the arm.

E. Specific Operational Problems Encountered During Testing

During the entire evaluation procedure a daily log was kept of informal observations. Specific problems encountered by the amputee during use of the experimental arm were derived from this log. They are grouped in the following sections according to the particular component of the prosthesis involved.

1. Elbow Unit

Speed of movement of the forearm over the lower range of flexion is too fast to permit precise control of its movements. Upon reaching about 100 deg. flexion the elbow exhibits a jerking movement and then slowly creeps over the remainder of the range. This movement can be seen in the curves of Figure 6. Apparently the physical configuration of the bellows within its support is responsible for an abrupt restriction in bellows expansion. Past the point of jerking the precision of motion is improved due to the reduction in speed. The reduction is so great, however, as to annoy the amputee. The jerking motion that occurs at 100 deg. also makes transport of liquids in open vessels difficult.

The elbow locking mechanism did not always provide a secure lock. In some instances the amputee was able to "lock" the arm at a position midway between two actual locking positions. This was due to a friction lock achieved by jamming of the locking pin against the gear mechanism of the elbow. When a load was applied to the forearm, such as in grasping a coffee cup, it was sufficient to depress the forearm enough to allow the pin to mesh with the gear, which it did with a loud thump. This was more of an annoyance than an actual hindrance in task performance.

A complaint often voiced during those tasks which involved motion at the face regarded a reduction of the upper flexion limit which occurred with reduction of gas pressure from the portable CO_2 source. While this reduction was only of the order of 5 deg. it was critical in view of the already severely limited upper range of elbow motion. This problem was compounded by the addition of a load (cf. Table 1).

Frequently on extension the amputee's motion was interrupted. This was mainly a problem with the standard above-elbow subject. It was due to a failure to maintain the proper tension in the control cable, thus permitting the control valve to slip backwards in the sequence of control positions, away from the position of extension (step 6).

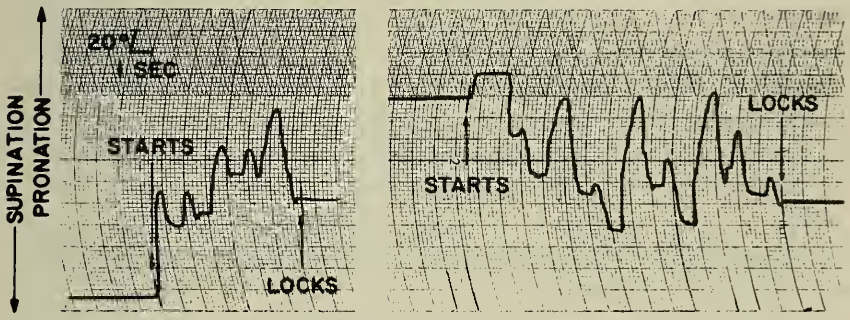
2. Wrist Unit

The wrist unit was by far the most difficult unit to control. Pronation speed was faster than supination, but both movements were apparently faster than could be easily controlled. Whenever possible in the standard

sequence tasks the amputees preferred to work out the optimum wrist rotation setting during the training period for the task and leave the wrist set at that position during the task performance. Only on the three tasks on which wrist activity could not be avoided did they rotate the wrist during the task.

Figure 29 illustrates the difficulty in controlling the wrist unit which was observed in precision of motion testing. The cost in time of using this unit was so high as to discourage the amputees from its use.

On initiation of supination movements the wrist exhibited what we termed a "pronation jerk," or movement of the wrist in the pronation direction before supination could begin. This artifact is illustrated in part (b) of Figure 29. It is caused by pronation spring's action upon unlocking of the wrist. This artifact was not critical in performance of the standard sequence tasks as performed here, but is an obviously undesirable feature of the wrist operation since it represents a built-in inadvertent movement of as much as 20 deg.



(a) Pronation trial. (b) Supination trial.

FIGURE 29. Samples of data of precision of motion tests with wrist unit.

In (a) amputee attempts to reach and lock at a test position 95 deg. away from starting position (extreme supination). In (b) amputee attempts to reach the same test position starting from opposite end of range of motion (extreme pronation). In both cases note large number of movements made, wide range of movement, and total time taken to reach lock (7 seconds and 14 seconds).

Pronation movements contribute more to performance variability with wrist unit than do supination movements. Most large errors are "overshoots" of test position on pronation. Also note in (b) that at start of trial there is an artifactual pronation movement as amputee unlocks wrist to initiate supination. This artifact occurred on nearly all supination trials.

3. *Terminal Device*

The terminal device was considered too bulky and clumsy by our amputees. Its size prevented its use in areas such as pockets, small purses, etc. It could not be used in close proximity to other objects since during grasp or release of one object often another was disturbed (for example, in the table-

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setting task in which utensils must be placed close together). Another frequent complaint related to size of the hand was that it frequently blocked the line of sight from amputee to object, depending on the orientation of the hand. Thus, information regarding approach to grasp and secureness of grasp was restricted.

The non-padded third finger adjacent to the two padded fingers protruded past the finger pads on the padded fingers and interfered with the grasp of small objects on the table top. For instance, a wooden pencil could only be grasped at the end rather than in the middle, if lying on a flat surface.

The amount of terminal device opening was a problem in two situations. In grasp of a round door knob, the opening was barely sufficient to permit grasp and then only in an awkward fashion. The available opening did not permit grasp at all of the standard cylindrical drinking glass. For our tests, we were forced to use a small (2-in. diameter) juice-type glass. Another solution would have been that of the Heidelberg training programs—use of a stemmed wine glass. A third solution, grasping the rim of the glass as is done by some hook wearers, was not feasible since the bulkiness of the hand prevented the amputee from bringing his mouth to the rim of the glass.

The orientation of the finger tip surfaces did not permit a secure grasp of a number of curved geometric shapes during training and testing. For example, the telephone receiver had to be jammed into the opening between the fingers in order to achieve a secure grasp.

Grasp of small, smooth metal objects such as the zipper tab was not secure and they often slipped from between the finger pads. Larger objects were grasped more securely.

III. SUMMARY AND RECOMMENDATIONS

A. Review of Subject Performance

Considering performance with the experimental prosthesis in comparison with the conventional prosthesis, we can summarize our findings as follows:

(1) Range of available motion was not substantially improved with the experimental prosthesis in spite of the addition of a new function (wrist rotation). Both range of flexion and of terminal device opening were noticeably less than those achievable with the conventional prosthesis.

(2) Initiation of movement with the experimental arm (complex reaction time studies) was much slower than with the conventional prosthesis. This result reflects several factors, including pneumatic time lags, the increased complexity of the control motions, and the greater number of choice alternatives.

(3) Precision of motion achieved with the various functions of the experi-

mental prosthesis was much poorer than with the conventional prosthesis, wherever a comparison was possible.

(4) Performance on a series of standardized tasks was much slower and showed more errors with the experimental prosthesis than the conventional. Similar results were obtained on a more difficult task conducted under the stress of a speed test.

Again we would like to emphasize the limitations of our conclusions. The comparison statements are based mainly on the results of performance tests of the standard above-elbow amputee, using performance with the conventional prosthesis as a baseline for comparison. In general, results of the forequarter amputee were found to parallel those of the standard above-elbow subject with the experimental arm, though they were somewhat better. As noted earlier, differences between subjects make inter-individual comparison difficult. Such differences here included level of amputation, control motions, age, physical condition, and previous prosthetic experience. Therefore, we can only consider the results obtained with the forequarter amputee as supportive data. His data would be best evaluated in terms of his own performance on another prosthesis.

The very limited nature of our sample as well as the high variability of performance obtained obviates the use of traditional statistical significance tests. Nevertheless, the levels of performance reported here represent a substantial investment in training time and experience and they can be considered as a reasonable representation of the performance obtainable with the experimental prosthesis.

This is not to imply that further improvement is not possible. On the contrary, the data of Figure 27 indicate that some learning was still occurring and that a complete performance asymptote had not been reached on the series of standard everyday tasks. However, a significant improvement in performance would only be expected after much additional training. The informal reports of Marquardt and Haefner (1957) regarding their training procedures seem to substantiate this point.

B. Operational Safety

Two points should be considered in regard to safety of the experimental prosthesis. First, the portable aluminum CO_2 source (German) does not meet United States standards of safety and there have been informal reports of explosions occurring during recharging. No such difficulty occurred with the steel cylinder used in this evaluation.

Second, the inability of the amputees to achieve positive and precise control of the prosthesis, coupled with the changes in operating speed which occur upon loading of the various components (pronation is an excellent example) made the arm unpredictable in some situations. One example is the refusal of the forequarter amputee to activate the wrist unit when

holding an object near the face. He developed this attitude after striking himself in the face more than once with a spoon during performance tests.

C. Functional Cosmesis

Regarding cosmesis, little direct attention was given to this aspect of the evaluation. In general, informal observations of amputee opinions indicate that their major concern was with the functional shortcomings of the experimental arm. Specific complaints concerned the jerky motions of wrist and elbow already noted. Also mentioned were the filling and exhausting noises occurring with stop and start of movement. These were judged to be more than loud enough to attract attention to the wearer.

D. Prosthesis Acceptance

The reactions of both subjects to the experimental prosthesis can be described as mixed. For the forequarter amputee this prosthesis represented a definite regain of functions lost to him after amputation. However, this was his first experience with a prosthesis that provided any appreciable motion. He frequently expressed feelings of frustration regarding his inability to achieve positive control and regarding the limited elbow range.

The standard above-elbow subject was less enthusiastic regarding the experimental arm initially, but expressed the feeling that with long term training and practice he would eventually reach an acceptable level of performance. Nevertheless, he expressed feelings of frustration and disappointment during use. His comparison basis was his own conventional prosthesis.

E. Initial Cost and Maintenance Cost

Although the Heidelberg Arm has been available to a limited number of European amputees for several years, it is not yet in production in this country and therefore generally unavailable to American users. Our latest information from the United States manufacturer, the Otto Bock Co. of Minneapolis, indicates that this prosthesis will be sold in the near future, but accurate cost estimates are not yet available. Maintenance costs can only be determined after the United States model is in use or is subjected to prolonged field testing. Our experience with the German model indicates that maintenance costs could be fairly high, depending, of course, upon the quality of components in the American model.

F. Systems Reliability

Repairs and maintenance necessary on the experimental prosthesis have been mentioned in various sections of this report. They will be reviewed here briefly as follows:

(1) Wear of the elbow bellows resulted in rupture of this component twice. Once the unit was replaced by the German developer; the

second occurrence was treated at the University of California at Los Angeles by use of a rubber patch.

(2) A ball-type pressure greaser in the 7-position control valve became worn and frequently jammed the operation of the valve.

(3) Clogging of pneumatic lines was a frequent event at the area of the control valve nozzles, requiring disassembly of the linkages. This problem may have been due to the use of a laboratory compressed air supply and might not occur if CO_2 is the sole power source.

(4) The terminal device finger pads became worn, requiring regluing a number of times.

(5) The rubber tubing broke during testing. Examination revealed the development of numerous small cracks probably due to atmospheric smog effects.

Expected downtime with the experimental arm during normal operation would be considerable in light of our experiences. Since the particular model of the arm tested here is of 1958 or 1959 vintage, there may have been recent improvements to design and especially to quality of components to increase reliability of the prosthesis. Nevertheless the prosthesis tested here was a production model, not a prototype or test model, and the difficulties reported, as well as a number of unreported minor incidents, would be expected in normal operation over a period of three to six months. Maintenance would be difficult in most cases for the amputee himself and the prosthesis would require professional care.

We should mention for comparison purposes that no serious mechanical problems occurred with the conventional prosthesis which was used under the same conditions of testing by the standard above-elbow amputee. This subject also used this prosthesis concurrently in his daily routine. Replacement was made to the terminal device fingers due to normal wear of the neoprene linings.

G. Recommendations

The following suggestions are made with regard to functional deficiencies of the experimental prosthesis as revealed in the evaluation testing. The emphasis here is on gross functional improvements rather than upon specific, detailed mechanical modifications or on other mechanisms for their implementation.

(1) The upper flexion range of the elbow unit should be increased to 135 deg. so as to permit activity in the face region with a minimum involvement of "body english."

(2) Maximum terminal device opening should be increased by an inch or more to increase the range of objects that may be grasped.

(3) Replacement of the terminal device by a hook would be desirable to

increase maneuverability in approach and grasp, and to increase the flexibility and variety of grasp orientations.

(4) Another approach to improving grasp, while retaining the present terminal device, would be to streamline hand and fingers, to increase size of opening, and to line with rubber the inner surfaces of thumb and fingers. In this way, objects could be grasped within the hand rather than at the fingertips only.

(5) Speed of movement and available force should be more nearly constant over the range of each movement and equal for both directions of movement. The extreme difference in pronation and supination speeds is an example.

(6) Movements should be smoother and positive at all times in the intended direction. The "creep" in the elbow unit at the upper flexion range, the jerky motion of supination, and the brief pronation movement occurring at the initiation of supination should all be eliminated.

(7) In addition to being slow, supination is a very weak movement. The forces available should be increased.

(8) Increased speed of initiation of each function would be desirable, since on the average it took over one second to initiate movement even in the simple reaction time situation.

(9) Precision of operation of the elbow and wrist would be improved by allowing locking to occur anywhere along the range of motion rather than only at fixed positions. Even more important in this regard would be a reduction in time of operation of the locking system. The "hunting" motion observed in our precision of motion tests result both from the necessity of finding a fixed locking position and of activating the locking system while the unit moves past the locking position. The amputee either had to initiate locking before reaching the locking point (thus "leading" the arm), or try to overshoot just enough so that the lock would be operating just as the unit returned past the locking point.

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ADULT CENTER CONTROL HOOK [a]

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INTRODUCTION

The design of an adult center control hook and the results of field testing the device on two amputees are covered in the following.

A center control hook is simply a hook whose control cable passes through the axis of the mounting stud. The advantages of this device over the conventional hook are its ability to be rotated or flexed at the wrist without a change in control cable excursion and the location of the control cable inside the forearm where it is not a hazard to clothing.

The VA Prosthetics Center is currently producing a limited number of these hooks for testing at other research centers in order to expand the evaluation program.

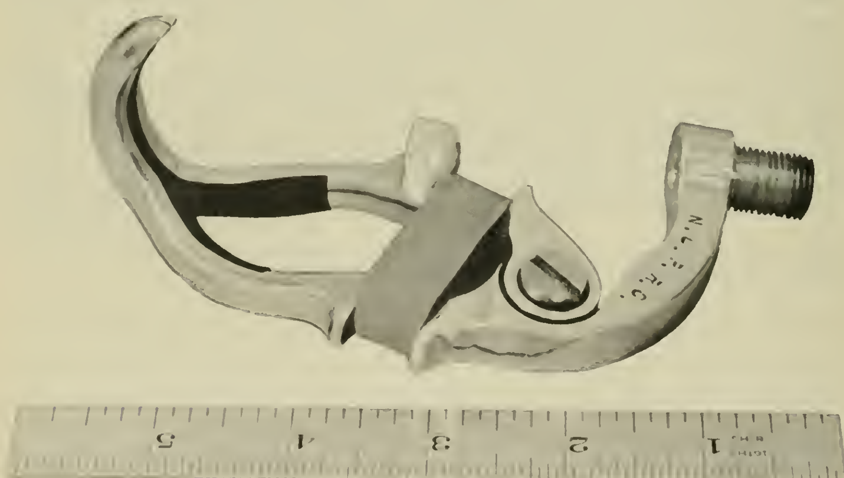

FIGURE 1

[a] Based on work performed under VA Contract V1005M–1079.

DESIGN

The prototype model was constructed by saw cutting the shape from 7075–T6 aluminum alloy, then filing and polishing to the final shape. Black neoprene rubber $\frac{1}{16}$ in. thick was bonded to the gripping surfaces using 3M adhesive EC–1300 (Fig. 1 and 2). The pivot contains a stainless steel screw and two ball thrust bearings to minimize friction with one set having races of concave cross section to maintain alignment. This is the same pivot system used in the Dorrance aluminum hooks. To allow the cable to pass through the center of the mounting stud, the pivot is offset $1\frac{5}{8}$ in. from the stud centerline. The tip of the hook fingers are set on the stud centerline, giving a radial deviation of approximately 25 deg. This allows the patient to approach an object with the hook in much the same manner as a normal hand (Fig. 3). The overall length is the same as the Dorrance #555 hook; however, for a given number of rubber bands, the force at the hook tips is approximately 10 percent greater due to the shorter distance from the hook tips to the pivot.

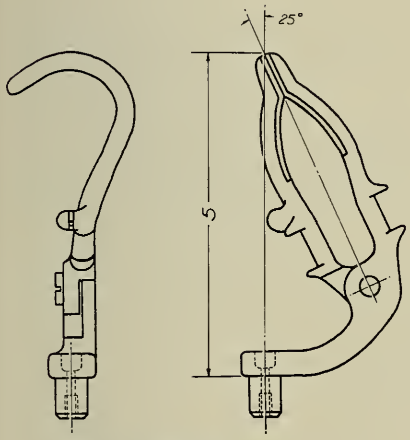

Figure 2

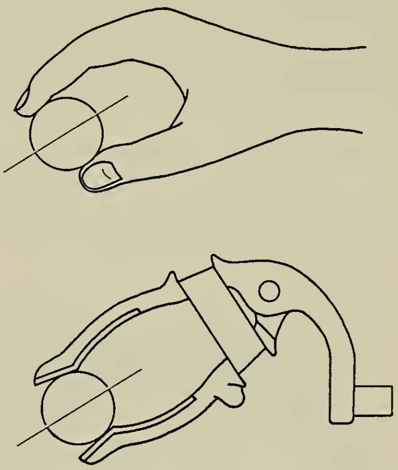

Figure 3

CASE HISTORIES

Case No. 1. F. L., a male right above-elbow amputee with a 9-in. stump, whose occupation requires only desk work, has been an active prosthesis wearer for over 20 years. The experimental hook was used for both business and social gatherings; he used no other terminal device during the 10-week test period. His initial reaction to the shape was a bit disconcerting because of its “lopsided feeling” as compared to his previous hook (Dorrance #555), however, within a few days this “feeling” disappeared. He

liked the ability of the hook to be easily rotated 360 deg. without change of cable excursion, and the absence of wear on shirt cuffs caused by a control cable. He felt that the absence of a "thumb" in no way detracted from its usefulness. He was very reluctant to surrender the hook and expressed a desire to wear one on a permanent basis.

Case No. 2. S.M., a male, right above-elbow amputee, is an active prosthetic wearer. He is employed by a hospital where his occupation requires desk work plus light manual labor. The experimental hook was the only terminal device used for the 9-week test period. He was very conscious of the "different" shape for a period of approximately four weeks, but felt that other people were unaware of this change in his terminal device. He liked the ability of the hook to be rotated without a change in cable excursion, and the inward slant of the fingers. He felt a thumb would be helpful, but not essential. The subject was reluctant to change back to his previous terminal device (Dorrance #555) and very anxious to obtain a center control hook if it were commercially available.

LIFT TAB POSITIONING JIG [a]

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INTRODUCTION

The dual control cable system for operating an above-elbow prosthesis consists of two separate cables: one cable operates the elbow lock, and the other cable positions the forearm and controls the terminal device.

Positioning of the forearm is accomplished by force exerted on the cable which is transmitted to a forearm lift tab. The lift tab position is selected to provide the best balance between force and excursion for the individual amputee. Distal placement requires low force and high excursion. Proximal placement requires high force and low excursion. Although each amputee is different, one publication suggests 1¼ in. from the elbow center as an average position (1).

Often, more distance is desirable when a new amputee is beginning to learn the operation of the prosthesis. After learning the operational sequence, if required, the position of the lift tab can be changed up to ⅜ in. closer to the elbow center.

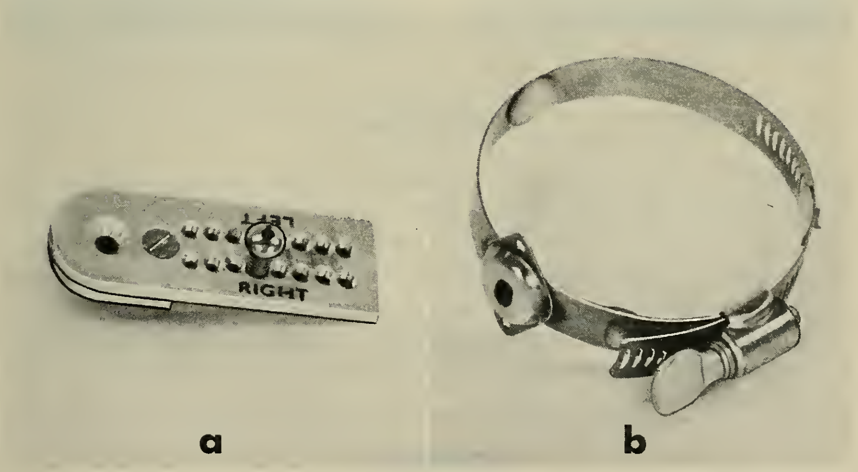

FIGURE 1

[a] Based on work performed under VA Contract V1005M–1079.

To provide for this adjustment during the harnessing and training process, the Prosthetic Research Center has devised an adjustable lift tab jig (Fig. 1a). When used in connection with a proximal retainer base plate jig (Fig. 1b) and a polyethylene lift tab, the best cable path can be experimentally determined and changed as operating skill increases.

INSTALLATION

The adjustable lift tab jig is designed for use with either Hosmer or Sierra elbow units. When used with Hosmer elbows, the lift tab jig indexes in the forearm lift assist hole; when used with Sierra elbows, it indexes into the indentation in the elbow saddle. The lift tab unit is installed by placing it in position at the elbow center and inserting the screw which normally retains the elbow saddle (Fig. 2).

Figure 2

Figure 3

PROCEDURE

To use the device, the prosthetist selects the best lift tab position. He then adjusts the proximal retainer clamp to provide the correct cable pathway. When a polyethylene lift tab is used, this can be punched at an average length and shortened as needed. The cable system can be checked out and reviewed by the clinic team during the control and use training phases and minor adjustments can be made. A permanent cable system can be installed as quickly as the clinic team feels that the best positions have been determined (Figs. 3 and 4).

REFERENCE

1. Manual of Upper Extremity Prosthetics, U.C.L.A., 1958, p. 169 (Installation of the A/E Dual Control System).

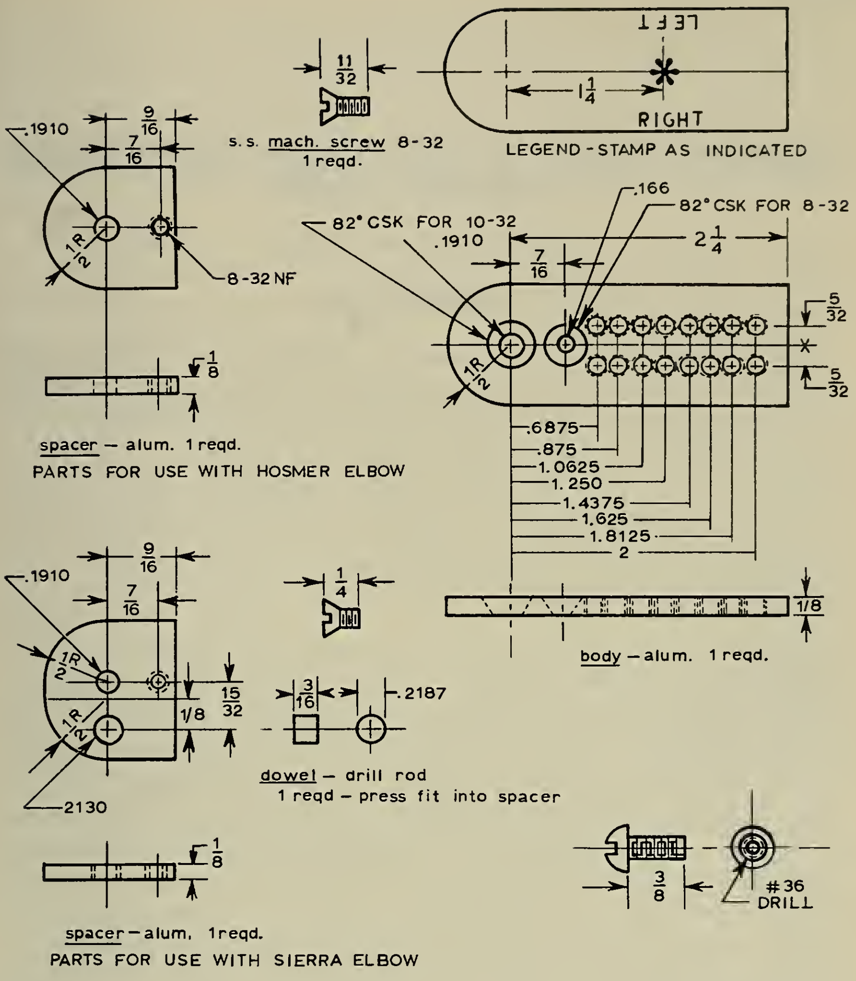
11/32
s. s. mach. screw 8-32
1 reqd.
LEFT
1 1/4
RIGHT
LEGEND-STAMP AS INDICATED
.1910
9/16
7/16
1R/2
8-32 NF
1/8
spacer — alum. 1 reqd.
PARTS FOR USE WITH HOSMER ELBOW
.166
82° CSK FOR 8-32
82° CSK FOR 10-32
.1910
2 1/4
7/16
5/32
5/32
1R/2
.6875
.875
1.0625
1.250
1.4375
1.625
1.8125
2
1/8
body — alum. 1 reqd.
.1910
9/16
7/16
1/4
1R/2
1R/2
1/8
15/32
3/16
.2187
2130
dowel — drill rod
1 reqd — press fit into spacer
3/8
#36 DRILL
1/8
spacer — alum. 1 reqd.
PARTS FOR USE WITH SIERRA ELBOW

FIGURE 4

SEMIANNUAL REPORT OF THE VETERANS ADMINISTRATION PROSTHETICS CENTER

(July-December 1965)

INTRODUCTION

The VA Prosthetics Center continues to emphasize development of pylon structures for "permanent" as well as "temporary" lower-extremity prostheses. The adjustable below-knee pylon has been engineered to the point where it is now ready for limited testing by others. Furthermore, with the cooperation of commercial production sources, development of suitable cosmetic covers is being achieved. With these efforts and with the planned development of the multifunctional above-knee pylon and the several methods of forming lower-extremity stump sockets, we look forward to a new artificial limb era in which the present wood, crustacean designs may be replaced by pylons with cosmetic covers and in which sockets will be achieved more directly, hopefully without plaster-of-Paris impressions. Perhaps later, sockets for the below-knee and above-knee levels may be made from prefabricated, pre-shaped blanks to receive final contouring, especially for a required distal "contact," during or after simple trials on the amputee.

We have long felt that the above-knee, swing-phase control problem had been solved. There certainly is no shortage of mechanisms on the market (ranging from the simplest constant mechanical friction device to the most functional hydraulic). However, there are still new items that require scrutiny. Such a device is the UCB Pneumatic AK Swing Control Knee, a system perhaps not as functional as the more complicated hydraulic devices but one that provides, in a simple way, a swing-phase control of benefit to a large segment of the amputee population.

Our research touches also on more fundamental areas. We seek some rationale on the employment of elastic hosiery and its effect on venous return. The relation between externally applied pressures and the physiological yield deserves attention.

We are now also urging the accumulation of more fundamental data on the early stages of ambulation of a new amputee. Our instrumented pylon was designed for use by those researchers who have observed clinical success in immediate post-surgical application of prostheses. But, we now call for some supplementary, objective data on changing patterns of weight-bearing and on the improved prosthetic control which we estimate accrues from either early ambulation or surgery employing tension myodesis or both.

We continue to review the developments of others in upper-extremity components, particularly those using external power. Our interest in stimulating developments in orthotics through our own still limited efforts never wanes. Shoes, shoe modifications, and plantar supports, by virtue of the huge clinical responsibility we have through our Orthopedic Shoe Program, continue to be orthotic "devices" requiring research in depth we have not yet achieved.

The wheelchair lately has become one of our primary concerns. Recent new developments made by a progressive industry have required us to look carefully at our own VA specifications which not only are outdated but suffer from specificity. We have adopted the "functional standard" in place of the limiting "specification" since we feel it imperative not to limit industrial improvements by requiring, for example, an axle to be X inches in diameter of Y material. Rather we shall ask that the axle provide a certain strength under standardized laboratory conditions replicating actual service requirements as nearly as possible. Thus, the manufacturer can chose his dimensions and materials as he wishes as long as the "functional output" meets our clinical need. Hopefully, we may now open our VA market to progressive improvements in wheelchairs not only for those whom we serve but for all disabled.

Meanwhile, we are still fascinated with the progress of the materials technology especially in relation to prosthetic-orthotic applications. Even though we now foresee the day when plastic laminates may be displaced by prefabricated socket blanks of other synthetic materials and when wood and its necessary plastic laminate reinforcement may no longer be required, we have been urged by Mr. A. B. Wilson of CPRD to check new fiber materials for lamination with the standard resins. It appears now that polypropylene cloth laminates may have a place in prosthetics and orthotics thus requiring the tests we describe.

The staff of our Center especially Henry F. Gardner and those people under the leadership of Dr. Edward Peizer deserve a great deal of credit for their continued productivity in research and development. Dr. Peizer's personal efforts in putting together the research report and those of Frank A. Witteck in preparing the operational data are sincerely appreciated and deserve recognition.

ANTHONY STAROS, *Director*
VA Prosthetics Center, New York, N.Y.

I. LOWER-EXTREMITY PROSTHETICS

A. Basic Studies

Effects of Compression of the Lower Extremity

B. Development (Components)

1. Adjustable Below-Knee Pylon for Temporary and Permanent Prostheses

I. LOWER-EXTREMITY PROSTHETICS—Continued
- 2. Multiplex AK Pylon
- 3. Instrumented Pylon
- 4. Torque Absorber

C. Development (Techniques)
- 1. Pneumatic Casting
- 2. Direct Forming of Below-Knee Sockets

D. Evaluation (Components)
UCB Pneumatic AK Swing Control Knee

E. Evaluation (Techniques)
Air-Cushion Sockets

II. UPPER-EXTREMITY PROSTHETICS

A. Development
None.

B. Evaluation (Components)
- 1. AIPR Externally Powered Components
- 2. Northwestern University Center Control Hook
- 3. Low-Friction Cable Transmission Systems

C. Evaluation (Techniques)
None.

III. LOWER-EXTREMITY ORTHOTICS

A. Development
Friction Ankle for Drop-Foot Brace

B. Evaluation
Foot Supports

IV. ORTHOPEDIC AIDS

A. Development
Functional Standards for Wheelchairs

B. Evaluation (Components)
- 1. Hydro-Crutch Model FP 2000–1
- 2. American Wheelchair
- 3. Gendron Lightweight Wheelchair (Model #8515–15)
- 4. Everest and Jennings Mono-Drive Wheelchair
- 5. Cetrone Contoured Support Belt

C. Evaluation (Techniques)
None.

V. TESTING

A. Specifications Compliance
- 1. SACH Feet
- 2. Stump Socks
- 3. Upper-Extremity Components

B. Materials
- 1. Luperco Catalysts
- 2. Polypropylene Reinforcing Fabric for Lamination

VI. OPERATIONS REPORT FOR FIRST HALF, FISCAL YEAR 1966

A. The Orthopedic Shoe Service

B. The Prosthetics-Orthotics Service

C. Special Service for Vietnamese Wounded

I. LOWER-EXTREMITY PROSTHETICS

A. Basic Studies

Effects of Compression of the Lower Extremity. Elastic hosiery is generally prescribed on the basis of girth measurements taken at various levels of the limb. Stockings may fit the leg properly and comfortably, but very little is known about the effects of compressive forces. Knit geometry and the ratio of elastic to non-elastic elements vary among the products of several manufacturers, and the magnitudes and gradients of the pressures they apply are unknown. Elastic hosiery should be prescribed on the basis of physiological indications of the optimal limits of compression. Valid physiological criteria will provide functional standards for evaluating currently prescribed elastic hosiery. Specifications can then be established to guide the fabrication of hosiery with regard to dimensions and the ratio of elastic to non-elastic elements.

This may be possible in terms of the basic relationship between circumferential tension (F) and compressive pressure (P_0). If we know: 1. the relaxed circumference of the stocking (C_2), 2. the circumference of the leg with the stocking on (C_1), and the elastic gradient (k) for the material and knit configuration of the stocking, we can calculate the compressive pressure (P_0). The standard formula for a thin wall pressure container is:

$$F=k(C_1-C_2),\ P_o d=2F,\ d=\frac{C_1}{\pi}$$

$$P_o d=2k(C_1-C_2),\ P_o=2k\,\frac{(C_1-C_2)}{\frac{C_1}{\pi}}$$

$$P_o=2k\pi\left(\frac{C_1-C_2}{C_1}\right)$$

Because the cross section of the leg is not a circle, these pressures will be modified: somewhat higher pressures will be applied to areas with a smaller radius of curvature, and slightly lower pressures to those with a larger radius of curvature.

A study has been initiated to develop simple and easily recorded physiological measures of the effects of compressive forces applied to the upper and lower segments of the leg. Measurable hemodynamic alterations induced by

raising the pressure applied to the venous tree of the leg may enable us to relate the pressures applied by elastic hosiery to changes in cardiovascular parameters.

The basic aspect of this study involves a search for an appropriate measure of compression effects. The underlying assumption is that substantial forces applied to the lower limb affect the venous return and hence, measurable effects might well be found in pulse rate, arterial pressure, and cardiac output. In the current phase of this study, pulse rate and pedis dorsalis, popliteal, and brachial arterial pressures as well as EKG signals are monitored on a series of normal subjects while the ambient forces on the lower extremities are altered: external pressures ranging from 1.0 to 1.2 atmospheres are applied to the leg which is simultaneously subjected to axial forces ranging from 0.0 g. to 1.0 g. Gravitational effects are altered by means of a tilt table, and atmospheric pressure is adjusted by means of a pneumatic pressure sleeve.

An identical study will be undertaken with wearers of elastic hosiery.

B. Development (Components)

1. Adjustable Below-Knee Pylon for Temporary and Permanent Prostheses. With the widespread use of temporary prostheses, clinicians are permitting patients to use these devices on an out-patient basis with increasing frequency. The temporary prosthesis should therefore be readily convertible to a cosmetically adequate permanent prosthesis.

Based on the early assumption that the prosthesis was "temporary"; i.e., it was very soon to be replaced by a "permanent" prosthesis, the requirements for these devices were simple. Low-weight and simple-to-use alignment adjustability were desired. In addition, for the immediate post-operative prosthesis, a convenient disconnect feature was required to permit the shank and foot section to be detached from the socket during bed rest and replaced without the loss of the original alignment.

However, the tenability of the original assumption is questionable. The line between "temporary" and "permanent" use is not well defined; the curve of increasing patient mobility during training is smooth and there are no lines of demarcation in *performance* to indicate a specific time of readiness for permanent, as opposed to temporary use. Generally, stump condition indicates the readiness of the patient for a permanent socket; when shrinkage is complete and the stump volume and contour are stabilized, little additional socket modification will be required.

Devices for use as both temporary and permanent prostheses must be designed for:

a. greater structural strength and durability,
b. simple alignment adjustability,
c. independence of alignment adjustments,

d. provision for incorporating the alignment device in a permanent prosthesis while permitting subsequent alignment adjustments,

e. cosmetic adequacy.

This evolution in thought has led to the development of a below-knee adjustable pylon designed to meet the needs of patients in the period immediately after fitting in surgery and for "permanent" use as well.

The below-knee system (Fig. 1) is designed for convenient attachment to any type of socket. If socket replacement is anticipated, the straps should be used for atachment while for permanent use, the socket may be glued or laminated to the block on the alignment device. The unit provides *independent*, self-locking linear adjustments in the anterior-posterior and the medial-lateral directions. It also permits separately controlled angular adjustments in the anterior-posterior and medial-lateral planes, up to 10 deg. The pylon and SACH foot are attached to the alignment section by an extremely rigid connection consisting of mating dovetailed sections which are easily disconnected by means of a single screw.

The foot attachment, permanently bonded to the pylon, provides for additional anterior-posterior linear adjustment. The pylon is also designed to receive and retain a cosmetic cover.

The pylon, the foot attachment, and the basic alignment system are also used in the above-knee device described below.

2. *Multiplex AK Pylon.* The design of a versatile pylon for above-knee prostheses has been refined by simplifying the method of installing various swing-control units, development of a specially adapted mechanical friction swing-control unit, and the design of a suitable cosmetic cover.

The upper attachment has been redesigned to receive the knee mechanisms. To preserve the varying geometrical relationships among the knee center and the upper and lower attachments of each hydraulic knee mechanism, a single adapter for each unit has been designed to position the lower attachment properly. The interchange of knee-control mechanisms simply requires the installation of the new unit at the same upper attachment point as the old, and the replacement of the old lower attachment adapter by a new one.

The design changes made to date have improved the ease of interchanging the several hydraulic units but have increased the difficulty of installing the Northwestern Disk Friction Unit. It was found more expedient to design a mechanical, adjustable variable friction knee unit which can be more readily accommodated in the pylon. This unit is still experimental.

A new cosmetic cover has been developed for both below-knee and above-knee use. Fabricated of lightweight flexible vinyl, the new cover is neutral in shape for use on either right or left side. This cover, which fits all SACH feet, is maintained in position by means of a distal sleeve through which the foot attachment passes (Fig. 2).

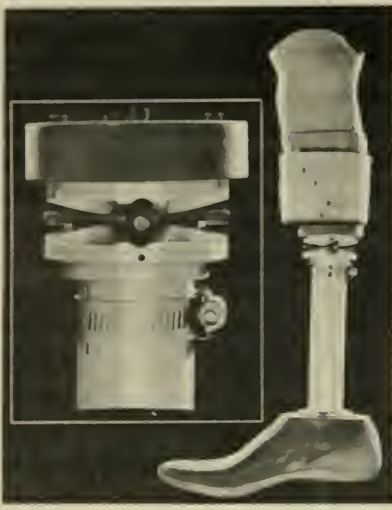

FIGURE 1. Experimental BK adjustable pylon in setup with socket, shank block, and SACH Foot. Inset shows multiple socket attachment screws and three of the four angular alignment adjustment screws.

FIGURE 2. New vinyl cosmetic cover for the experimental Multiplex AK pylon. Neuter shape permits use on either right or left side, and the attachment to the foot has been improved.

3. *Instrumented Pylon.* Gait parameters and the effects on patient performance of prosthetic fitting, alignment, and functional components are most accurately and objectively studied by means of photometric and electronic instruments. For many years, force plates and interrupted light cameras have been used for this purpose since they provide data on many of the forces interacting between the foot and the ground in stance phase and on the position of the major lower-extremity joints in both swing and stance phase. Despite the extremely valuable data provided by these systems, a great deal of work is involved in: a. preparing the equipment, b. targeting patients, and c. making multiple runs to assure that the entire foot is on the force plate during stance phase. There are also difficulties attendant on correlating photographic and electronic data. While these problems are inescapable in obtaining these data, we rarely require the full range of information. For example, only axial loads and knee moments may be required for studies involving the use of above-knee swing-control devices or perhaps, torque data alone may be required as a basis for the development of a torque-absorbing component. To provide greater selectivity, to simplify the collection and reduction procedures, and to reduce our dependence on the fixed walkway and force plate, we have developed an instrumented pylon which provides many of the outputs previously

obtained by the present systems. It is basically similar to a device developed at the University of California some years ago.

This unit (Fig. 3), designed for installation in the shank of either a below-knee or above-knee prosthesis, can be used on any walking surface. Thus, it is unnecessary to require the subject to strike a fixed plate properly, permitting studies to be performed in different locations. The pylon system can be used with all standard amplifying and recording equipment.

Twenty-four strain gages are arranged in circuits to respond to axial load, torque, and both anterior-posterior and medial-lateral shear. Knee moment is determined from the differences in the magnitudes of gage outputs at three levels on the pylon, yielding the slope of the moment curve along the axis of the pylon. By electronic extrapolation of the slope, knee moment is attained.

This device has been especially designed for use in a series of studies to determine the effects on gait of SACH foot heel wedges of varying density, anterior-posterior and medial-lateral placement of the foot with respect to the shank, knee joint alignment, and socket weight-bearing characteristics. The instrumented pylon will also be used in the Seattle [a] studies to record the daily change in weight-bearing pattern of patients fitted immediately after surgery.

4. Torque Absorber. In a series of tests the previously designed torque absorbing device (BPR 10–3, Spring 1965, p. 109) performed reasonably well, but its structural strength was inadequate and it was too bulky. The unit has been redesigned to employ the principle of the "Lamiflex" bearing (Fig. 4), a commercial product of the Marlin-Rockwell Co.

Twelve Lamiflex torque absorbers were constructed to the following specifications: a. each unit must develop a resistance torque around the axis of the assembly of 50 in.-lb.±10 percent at an angular displacement of 15 deg. either side of center with approximate linearity in this property as a function of the angle; b. the complete assembly must withstand a pressure of 1100 p.s.i. at its outer edge without failure of the bonding at any point.

These specifications were drawn from biomechanical data obtained on both normal and pathological gait.

After mechanical tests are completed to determine their compliance with the specified physical properties, these units will be installed in prostheses worn by several patients.

C. Development (Techniques)

1. Pneumatic Casting. Producing a negative form for a socket mold by external-pressure-casting techniques has been the object of several studies in

[a] VA Prosthetics Research Study, Seattle, Washington.

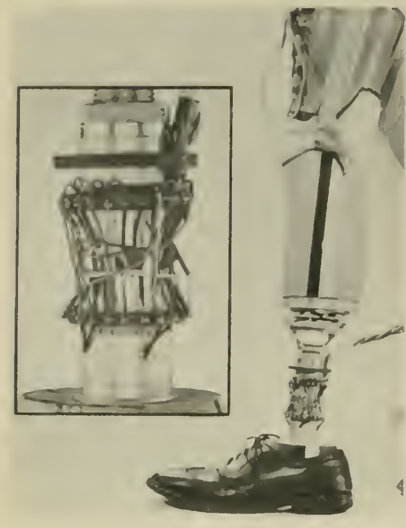

FIGURE 3. Instrumented pylon is installed as shank of a BK prosthesis and aligned by means of VAPC coupling. Inset shows wiring details: black disk in center is a rosette strain gage arrangement which is sensitive to torque; on the lower part of the pylon are shown two temperature compensating gages.

FIGURE 4. Torque absorber installed in the shank of a BK prosthesis below the BK alignment device. In the inset, the bearing material "Lamiflex," consisting of alternate layers or resilient rubber sheets and resistant metal sheets, is shown sandwiched between an upper and lower plate.

the past. Among others, Mr. Paul Leimkuehler of Cleveland, Ohio, devised a vacuum system for this purpose; hydraulic methods for pressure casting were developed by Mr. Colin McLaurin while with the VA project at Northwestern University, and by Mr. Theodore C. Meyer of Detroit, Michigan.

For various reasons these techniques were never fully developed. In searching for a method of controlling stump casting pressures, VAPC reviewed these experiences and developed a pneumatic casting procedure (BPR 10–3 Spring 1965).

During the past year, 70 male below-knee amputees have been fitted with prostheses made from casts obtained by the pneumatic pressure system. In all, 77 casts have been made for these 70 patients, including 7 bilaterals, a fairly typical sample of veteran amputees.

The subjects ranged from 20 to 85 years of age, with 55 of them between 41 and 70 years of age. Height ranged from 5 ft. 2 in. to 6 ft. 2 in. with 62 of the 70 between 5 ft. 7 in. and 5 ft. 11 in. tall. Fifty-nine subjects weighed between 161 and 200 lb. while ten weighed between 120 and 160 lb. and one weighed 245 lb.

Thirty-three patients had amputations due to accidents or gunshot wounds, 33 due to vascular pathology, and 4 to osteomyelitis.

Occupations ranged from professionals to unskilled laborers. However, more than half the sample were found to be clerks (13), skilled workers (10), or retired (16).

The 44 previous prostheses wearers, primarily World War II veterans, included 2 World War I veterans. Of the 70 subjects, 38 became amputees between 1961 and 1965.

Fifty-five stumps were between 5 and 7 in. long, 9 were between 3 and 4 in. long, and 13 were longer than 7 in. The sample is described in Table 1.

A description of the amputees' previous prostheses is given in Table 2. Thirty-four limbs had PTB sockets, 12 of which used cuff suspension with the remaining having lacer suspensions. Twenty-six cases, representing 31 stumps, had no prostheses previously.

TABLE 1.—*Summary Description of Patients*

(Seven Bilateral Amputees Included in Sample)
N=70

Range data			Etiology			Stump length, in. N=77		
Age, yrs.	Height, in.	Weight, lb.	Wounds or accidents	Vascular	Osteomyelitis	3–4	5–7	8–10
20–85	62–74	120–245	33	33	4	9	55	13

TABLE 2.—*Description of Previous Prostheses*
N=77

No Previous Prosthesis	31
Cuff Suspension, PTB, Closed End, Liner	8
Cuff Suspension, PTB, Hard, Soft End	3
Cuff Suspension, Hard, Open End	1
Lacer, Side Joints, Hard, Soft End, PTB	1
Lacer, Side Joints, Hard, Open End (Non PTB wood)	12
Lacer, Side Joints, Soft, Closed End, PTB	3
Lacer, Side Joints, Soft, Open End, PTB	18
Total	77

Conventional alignment techniques were employed in fitting these patients. Either an adjustable coupling or one of the currently available below-knee temporary pylons was used during alignment and fitting trials. The pressure casting apparatus, described in BPR 10–3 Spring 1965 was employed and

stumps were cast over three below-knee cast socks with the outer one forming part of the cast. A casting pressure of 2 p.s.i. was maintained for ten minutes. Forty-two of the sockets were used with typical PTB (cuff) suspension and 35 with conventional below-knee (lacer) suspension, as shown in Table 3.

It was quite clear that the pneumatic pressure casting technique produced highly satisfactory casts and sockets. They were well fitted and comfortable. The preponderant majority of sockets required little or no significant modifications.

As shown in Table 4, all the plaster socket molds required buildups ranging from ¼ to ⅜ in. on the distal end. However, of 77 sockets, 62 required no further modification, 12 were modified by additional relief for the end of the tibia, and 3 required other corrections.

Table 3.—*Description of New Protheses*

(All PTB Sockets)
N=77

Cuff Suspension, Closed End, Liner	3	
Cuff Suspension, Hard, Soft End	7	
Cuff Suspension, Hard, Open End	28	
Cuff Suspension, Soft, Open End	4	
Total Cuff Suspension		42
Lacer, Side Joints, Hard, Soft End	0	
Lacer, Side Joints, Hard, Open End	4	
Lacer, Side Joints, Soft, Open End	29	
Lacer, Side Joints, Soft, Closed End, Liner	2	
Total Lacer Suspension		35
Grand Total		77

Table 4.—*Mold Modifications and Socket Corrections*

Plaster Mold Modifications	Socket Corrections
17 Molds: ¼ in. build-up end of tibia. 60 Molds: ⅜ in. build-up end of tibia.	12 Sockets: Relief for end of tibia. 2 Sockets: Relief for medial condyle. 1 Socket: Relief for medial hamstring. 62 Sockets: Required no corrections.
Total 77	Total 77

Evaluating these experiences, we find the pneumatic pressure casting method offers several advantages over more conventional methods. This technique permits the selective application of higher pressures to pressure-tolerant stump areas and lower pressures to the soft fleshy areas. More accurate replication is possible through reduction of sizing errors; different prosthetists will produce almost identical casts of the same stump after they have been familiarized with the technique. The casting method can be applied to fabricate a variety of sockets: all kinds of sockets including hard or soft, open end or closed end, and temporary plaster sockets can be fabricated over molds from stump impressions made by the pneumatic system. Relatively inexperienced technicians readily learn the procedures, and extensive mold modifications (plaster removal, plaster build-ups) are not required.

We intend to use the pneumatic method routinely for casting below-knee stumps while continuing our efforts to improve the technique and the equipment.

2. *Direct Forming of Below-Knee Sockets.* Experimental work has continued in an attempt to identify a dimensionally stable material which can be formed into sockets directly on the stump. Eight materials have been evaluated for this purpose, including several polyesters, acrylics, and polyethylenes. They were found to be unsuitable in that either excessively high molding temperatures were required or their characteristic "memories" did not permit them to retain the required contour.

A new material, the most promising to date, is under study. "Orthoplast," manufactured by the Johnson and Johnson Company, is a thermoplastic vinyl. Heated in an oven at 200 deg. F., the material is extremely pliable and capable of being molded very intimately over irregular surfaces. Heat is given off very rapidly and the material can be applied to the stockinet-covered stump within a minute after removal from the oven without causing undue discomfort to the patient. However, working time is relatively short, about two or three minutes.

Although "Orthoplast" is not yet available in cones for stump casting, experimental applications are being carried on with cones fabricated by hand from flat sheets.

D. Evaluation (Components)

UCB Pneumatic AK Swing Control Knee. A revised model (Fig. 5) of the pneumatic swing-control unit developed by the VA project at the University of California at Berkeley Biomechanics Laboratory is currently under evaluation. The unit is designed to provide smooth control of swing phase.

The operative element is an air piston/cylinder unit similar in function to a pneumatic door closer. Flexion of the prosthetic knee causes the pivot

located at the rear of the knee joint to move distally in the shank forcing the piston into the cylinder. This downward motion of the piston results in compression of the air below the piston and the creation of a partial vacuum above it. The pressure difference thus formed provides resistance to knee flexion. An adjustable by-pass flow of air from the pressure side of the piston to the vacuum side also modifies the resistance pattern. Extension of the knee from a flexed position results in similar resistance to extension as the pressure/vacuum relationship on the two faces of the piston and the controlled air flow are reversed.

The seven units received for evaluation will be subjected to a series of mechanical tests to determine resistance characteristics and durability. Also to be studied are the basic alignment and fitting requirements and the adequacy of installation instructions. Biomechanical analyses of performance will be undertaken on three subjects to evaluate the following claims made by the developer:

a. The setup allows more than 120 deg. of flexion which is considered optimum.

b. The resistance provided by the pneumatic knee is proportional to the lower ranges of walking speed, but due to its nonlinearity, effectiveness at higher speeds of walking is decreased.

c. The pneumatic unit offers, in addition to its damping effects, a positive kicker action. In resisting flexion, air is compressed and some of the energy thus stored is then spent in accelerating the shank forward into extension.

d. Less maintenance is required.

E. Evaluation (Techniques)

Air-Cushion Sockets. The air-cushion patellar-tendon-bearing socket developed by E. Lyquist et al.[b] at the University of California, San Francisco-Berkeley, consists of an external, rigid, polyester-laminate shell and an internal, elastic, silicon-rubber-laminate sleeve joined at the level of the tibial tubercle. The rigid socket shell provides direct support for the stump area proximal to the level of the tibial tubercle and extends distally on the outside of the elastic sleeve to about 1 in. above the distal end of the tibia. The elastic sleeve encloses the distal part of the stump beginning at the level of the tibial tubercle. A polyester-laminate cap, bonded to the outside of the distal portion of the rigid socket shell, provides a sealed air chamber distal to the elastic sleeve.

At the recommendaton of the Committee on Prosthetics Research and Development's Fourth Workshop Panel on Lower Extremity Fitting, held

[b] Lyquist, E., Wilson, L. A., and Radcliffe, C. W.: Air-Cushion Socket for Patellar-Tendon-Bearing Below-Knee Prosthesis. Biomechanics Laboratory, University of California at San Francisco-Berkeley Technical Memorandum, April 1965.

July 1965, several air-cushion sockets were fitted at VAPC to obtain information on the fabrication requirements and application indications for the prosthesis.

To date, a total of eight air-cushion sockets have been fitted. Three were fabricated over molds by the method recommended by UCSF and five were fabricated over molds obtained by the VAPC pneumatic pressure technique.

Preliminary results indicate that the air-cushion socket for the patellar-tendon-bearing below-knee prosthesis requires considerably more time to fabricate than does the conventional PTB socket. Moreover, socket modifications required after an initial period of wear, can only be completed at considerable cost in time and materials.

To warrant the increased complexity of fabrication and the additional cost in labor, the air-cushion socket should provide a level of comfort of function which is superior to conventional prostheses. Our experience to date provides no evidence to support the superiority of the air-cushion socket, at least on the type of stumps fitted at VAPC.

Of the eight patients fitted with the air-cushion socket, two subjects rejected it completely because of an inability to tolerate end bearing and three subjects are wearing their legs on a part-time basis for the same reason. The remaining three subjects continue to wear the air-cushion sockets full-time. We shall provide continued assistance to the developer by additional fittings as indicated.

II. UPPER-EXTREMITY PROSTHETICS

A. Development

None.

B. Evaluation (Components)

1. AIPR Externally Powered Components. The program designed to evaluate the CO_2-powered components developed by the American Institute for Prosthetic Research has proceeded through step g of the evaluation program described in the previous issue (BPR 10–4 Fall 1965). In the previous step (f), the subject's right prosthesis (humeral neck) had been completely powered by the installation of a pneumatically operated terminal device and wrist rotator and a powered elbow. In step g, a powered terminal device and wrist rotator and a passive shoulder abduction joint with power lock were also installed in his left prosthesis. Thus, the subject was bilaterally fitted with the full complement of powered components.

After an initial period of controls training, the subject returned to his home station for additional training in the performance of practical daily activities.

After a three month period of wear, the subject's performance was re-evaluated in the Laboratory. The test results (Table 5) indicated that little functional improvement had taken place in the interim with respect to time required to perform a standard task, number of errors committed, or in energy expenditure. The number and type of self-care activities that the subject was capable of successfully accomplishing had not changed appreciably. The performance of the patient had apparently stabilized at the level he previously achieved when the more mobile right side was fitted with the powered components and the left side with conventional components (step f).

TABLE 5—*Summary of Test Results* (*Right Prosthesis*)

Tests	Complete power on right side only (step f)	Complete power bilaterally (step g)
Prehension		
Total time, min.	4.8	4.7
No. of errors	14	6
Appearance	Poor	Average
Positioning		
Total time, min.	7.5	6.5
No. of errors	2	3
Appearance	Good	Good
Practical activities (7 tasks)	6 completed 1 failure	6 completed 1 failure
Net energy cost of 2nd prehension test	.955 liters O_2	1.685 liters O_2
Total time, min.	4.4	4.1
No. of errors	6	10
Appearance	Average	Poor

Since the subject has reached a plateau in the training/achievement curve, we have terminated the experimental portion of this study even though we recognize that some additional improvement might be expected from refitting the subject with new sockets.

The patient has been scheduled for "final" clinical evaluation to determine the best possible admixture of powered and conventional components. On the basis of a thorough analysis of his experience and performance patterns, he will be refitted with new prostheses. Thereupon, a final report will be presented on this case. Some tentative conclusions on the use of AIPR powered components as well as external power generally will be delineated.

2. *Northwestern University Center Control Hook.* "Center control" hooks, designed principally for operation by external power, are aimed at improving prosthetic cosmesis by eliminating the protruding operating lever and the external control cable. The hook fingers are operated by means of a control cable which runs through the hook stud and wrist unit into the forearm of an above-elbow prosthesis or the socket of a below-elbow prosthesis for a relatively short stump. The Northwestern University Center Control Hook is simple if somewhat unconventional in design (Fig. 6). The hook employs the same pivot as the Dorrance aluminum hooks, but it is offset 1⅝ in. from the stud centerline to allow the cable to pass through the stud center. The fingers are set in approximately 25 deg. of radial deviation. Two prototypes, inexpensively made from a casting alloy, are being studied to evaluate installation and requirements, function, patient reaction to appearance, and utility.

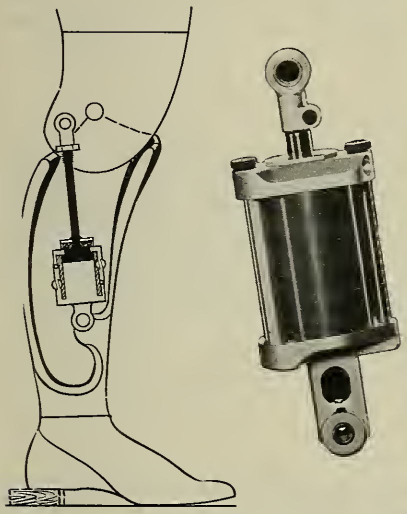

Figure 5. Drawing of the UCB Pneumatic AK Swing Control Knee showing the geometric relationship between knee center and points of attachment for the device. As the piston rod (solid block) moves distally when the knee flexes, air in the cylinder is compressed and driven upwards to the partially evacuated chamber above. Flow rate and thus resistance to flexion are adjusted by means of the valves. Inset shows simplicity of design.

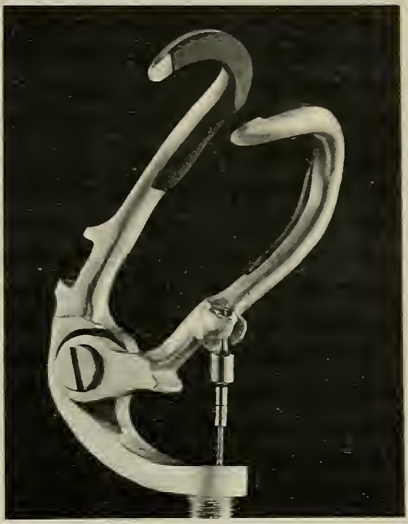

Figure 6. Northwestern University Center Control Hook fabricated in aluminum for test purposes. Principal features are angulation of the hook fingers, control cable attachment, and retaining slots for rubber bands.

3. Low-Friction Cable Transmission Systems. Two low-friction transmission systems, one developed by Northwestern University Prosthetic Research Center and the other by the Army Medical Biomechanical Research Laboratory, were evaluated.

The NUPRC system consists of a $\frac{1}{16}$ in. steel cable in Teflon "spaghetti" tubing (No. 13 AWG). The cable housing and other components are classed as "heavy duty." The Teflon tubing containing the cable is inserted into the cable housing, and the ends are flared.

The AMBRL system consists of Dacron cord, Teflon housing, and nylon ball and harness connectors. Two types of nylon retainers (Specimens A and B) are available; both were tested.

A comparative analysis was undertaken to compare both AMBRL systems and the NUPRC system with a "conventional" Bowden cable transmission system. Samples of the NUPRC system, both of the AMBRL systems, and a conventional transmission system were fabricated in 18-in. lengths with 12-in. lengths of cable housing, and with harness hangers and large ball terminals.

TESTS

Three tests of tensile strength were employed. In Test No. 1, designed to identify the "weak link" in the entire system, the steel harness connector end of the cable system was attached to the lower test grip, and the large steel ball end (with ball receiver) was attached to the upper test grip. Test No. 2 was designed to measure the tensile strength of the connection between cable and ball fitting. It was performed with the ball receiver omitted and the ball attached directly to the upper test grip. In Test No. 3, used to measure the tensile strength of the cable alone, the cable was attached directly to both upper and lower test grips.

All of these tests were performed at a cross head speed of 0.2 in. per minute, the same speed employed in previous tests conducted at AMBRL.

The AMBRL, NUPRC, and conventional systems were cycled 25,000 times on the fixture shown in Figure 7 to determine durability and frictional characteristics. Durability was determined on the basis of cable wear, and frictional characteristics were determined on the basis of efficiency of force transmission.

Efficiencies of the transmission system were determined by measuring the force required to lift a 4-lb. load. The test was performed once with the cable flexed 135 deg. to simulate maximum elbow flexion and again, without curving the cable, to simulate full elbow extension. Efficiencies, calculated by dividing the load by the lift forces, were expressed in percents.

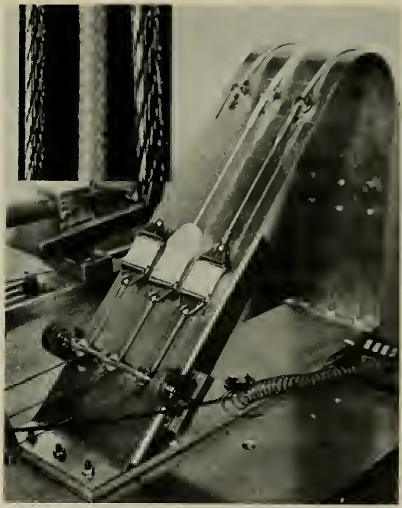

FIGURE 7. Test fixture employed to cycle the AMBRL, NUPRC, and a conventional cable control system to test durability and frictional characteristics.

TEST RESULTS

a. AMBRL Systems

1. Tensile Strength. In Test No. 1 of Specimen A, employing the entire system, the nylon ball pulled out of the steel receiver under a load of 48 lb. In Test No. 2, omitting the ball receiver, the Dacron cord cable broke at the knot within the nylon harness connector under a load of 56 lb. In Test No. 3, employing only the Dacron cord, failure occurred at the point of attachment (knot) at 63 lb.

Elongation under these tensile loads is shown below:

Test No.	Load in pounds	Elongation, percent
1	48	9.4
2	56	10.6
3	63	13.2

The efficiency of force transmission was 81 percent in a flexed position and 95 percent in the extended position.

Identical tests conducted with Specimen B gave essentially similar results, the chief difference being that failure occurred at somewhat higher loads in Tests No. 2 and No. 3 (2 percent higher in Test No. 2 and 17 percent higher in Test No. 3). Tension tests conducted by AMBRL resulted in higher strength values, 97 lb. versus 63 lb. for Specimen A and 116 lb. versus 78 lb. for Specimen B. This discrepancy can only be accounted for on the basis of variations in the test samples.

Elongation and efficiency of force transmission on Specimen B were identical with Specimen A.

2. Durability. Both AMBRL systems withstood the effect of 25,000 cycles without failure. However, as shown in Figures 8 and 9, the Teflon

FIGURE 8. Photograph of Dacron cord cable used in AMBRL system before cycling.

FIGURE 9. Photograph of Dacron cord cable at completion of 25,000 cycles.

housing showed moderate wear with consequent adherence of Teflon particles to the Dacron cord.

b. NUPRC System

1. Tensile Strength. In Test No. 1 employing the entire system, including the terminal connectors, the steel ball pulled out of the receiver under a load of 95 lb.

In Test No. 2, omitting the receiver, the cable pulled out of the swaged harness connector under a load of 310 lb. In Test No. 3, employing only the cable, failure occurred at the point of attachment to the test grip under a load of 490 lb.

Elongation under these loads was minimal, approximately 0 to 1.5 percent.

Efficiency of force transmission ranged between 78 percent in a flexed position to 93 percent in an extended position.

2. Durability. After 25,000 cycles under a 4-lb. load, the NUPRC cable caused excessive wear of the Teflon liner. Although no measurable wear of the cable occurred, the excessive wear on the liner may decrease the efficiency or the life of the system.

SUMMARY

Shown below in Table 6 is a comparison of all test results for the four configurations.

TABLE 6.—*Elongation, Tensile Strength, and Efficiency of Four Upper-Extremity Cable Transmission Systems*

System	Elongation, percent (approx.)	Tensile Strength, lb.			Efficiency, percent	
		Test No. 1, Total system	Test No. 2, Without ball receiver	Test No. 3, Cable only	Flex.	Ext.
Conventional (Standard) 3/64 in. steel cable, standard housing, heavy duty steel components.	0–1. 5	95 Steel ball pulled out of receiver.	255 Cable pulled out of swaged harness connector ball fitting.	340 Cable broke at point of attachment to lower test grip.	71	90
NUPRC 1/16 in. steel cable, Teflon spaghetti tubing No. 13 AWG, heavy duty steel components.	0–1. 5	95 Steel ball pulled out of receiver.	310 Cable pulled out of swaged harness connector ball fitting.	490 Cable broke at point of attachment to lower test grip.	78	93
AMBRL: Specimen A Dacron cord (sand and green colored), Teflon housing, nylon components.	9–13	48 Nylon ball pulled out of steel receiver.	56 Dacron cord broke at knot within nylon harness connector.	63 Cord broke at point of attachment (knot).	81	95
AMBRL: Specimen B Dacron cord (sand colored), Teflon housing, nylon components.	9–13	48 Nylon ball pulled out of steel receiver.	60 Dacron cord broke at knot within nylon harness connector.	78 Cord broke at point of attachment (knot).	81	95

In cyclic tests of wear, all four systems withstood 25,000 cycles under 4-lb. loads without failure.

The AMBRL system appears to be of inadequate strength for normal adult amputee use but it may be adequate for the child amputee. Although the efficiency of the Dacron cord in the Teflon housing was somewhat higher than steel in Teflon housings, the chief deficiency in the AMBRL system is the excessive elongation under load. The ease of assembly by simply knotting the cord may be advantageous but it does not overcome the deficiencies of low tensile strength and excessive elongation.

The NUPRC system is quite comparable to the conventional transmission system providing greater resistance to tension force primarily as a consequence of the greater cable diameter, $1/16$ in. versus $3/64$ in. Although it is approximately 10 percent more efficient than the conventional system, excessive wear of the Teflon liner may affect its life.

C. Evaluation (Techniques)

None.

III. LOWER-EXTREMITY ORTHOTICS

A. Development

Friction Ankle for Drop-Foot Brace. Designed to prevent the foot from dropping during swing phase, this device (Fig. 10), described in BPR 10–4 Fall 1965, employs friction disks at the ankle joints. The friction ankle joints are mounted distally in a contoured polyester laminate shoe insert designed to improve the cosmetic appearance of the brace by eliminating external stirrups. The proximal sections of the joints are mounted in polyester uprights. The insert can be shaped to influence foot balance.

In an experimental unit worn by a subject for four weeks, the laminate fractured at a point below the ankle joint as a result of the high resistance requirements. The friction setting loosened continually with wear and it required frequent readjustment. However, the patient considered the resistance superior to several other appliances he had previously worn.

We have, therefore, redesigned the unit to improve the friction resistance and the resistance of the laminate to fatigue.

B. Evaluation

Foot Supports. In continuation of our studies of the effects on both comfort and foot balance of various types of arch and foot supports, three subjects are each being fitted with three different appliances: a. leather Schaefer plates, b. Silverman heel stabilizer which is a shoe insert designed to prevent foot imbalance, and c. a dynamically contoured (weight bearing) plantar mold. Patient reactions are periodically recorded and objective data on foot balance and weight application to the plantar surface of the foot are being obtained by means of the barograph and motion pictures.

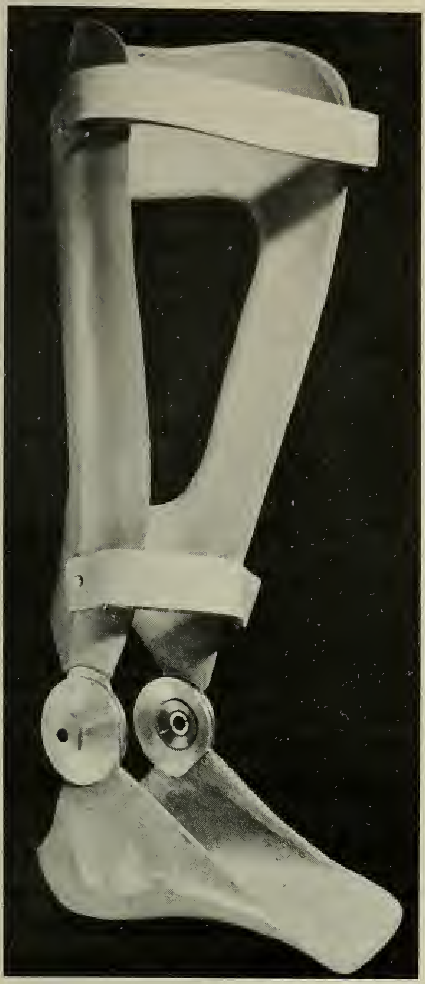

FIGURE 10. An earlier model of the friction ankle for drop-foot braces showing details of friction disks.

IV. ORTHOPEDIC AIDS

A. Development

Functional Standards for Wheelchairs. A great deal of interest has recently been generated in the design and development of wheelchairs, particularly as in the use of new materials such as lighter metals. As a consequence, we have seen during the last few years several new models featuring lightweight aluminum or stainless steel frames, solid polycarbonate casters, and a variety of synthetic upholstery materials. Existing VA Specification (7043400b) have become increasingly outdated and their utility in evaluating new wheelchair designs has decreased correspondingly. Based on our experiences in testing and evaluating approximately 12 new wheel-

chair designs, we are recommending revision of the current VA specifications in order to recognize the increasing use of new materials and to facilitate the evaluation of function and durability. We have recast them in the form of *functional requirements* to permit wide design variations while meeting VA standards. The tentative standards for wheelchairs are currently being evaluated by the chiefs of a number of VA Spinal Cord Injury Services and other interested individuals.

B. Evaluation (Components)

1. Hydro-Crutch Model FP 2000–1. This device is currently being redesigned by the developer to eliminate the deficiencies revealed by the evaluation program (BPR 10–4 Fall 1965). Negotiations are under way to purchase the improved devices for clinical field testing in several VA stations.

Following reevaluation of the new models at the Bioengineering Research Service, they will be sent to several stations where their utility for a variety of patients will be observed.

2. American Wheelchair. An evaluation program was completed on three modernized models of the American Wheelchair. These new chairs were distinguished by four unconventional features: a. 8-in. Lexan polycarbonate casters, b. plastic skirtguards, c. plastic leg rest panels, and d. readily detachable padded plastic upholstery.

Despite its departure from existing VA specifications, particularly as regards materials and the dimensions of certain components, these chairs met the functional requirements implicit in our proposed specifications. The Lexan wheels withstood the durability and impact tests but observation of long-term use may be required to be certain of their adequacy. Certain apparent deficiencies noted in this evaluation have been brought to the attention of the developer. Moreover, we are now planning to participate (with the Research and Development Division of PSAS) in a controlled field evaluation of a number of new and old wheelchair designs. This clinical study will assist us in the further development of the functional standards (described above) as well as in determining field reaction to the several designs.

3. Gendron Lightweight Wheelchair (Model #8515–15). Two lightweight wheelchairs were reevaluated to determine the effectiveness of modifications made by the manufacturer to strengthen the chair as a result of earlier testing which had revealed structural weaknesses. The revised models met all the specifications relating to strength and durability. However, several other apparent deficiencies were noted during clinical tests in which the chairs were used by patients in two VA stations. These matters have been brought to the attention of the manufacturer together with recommendations for improvement.

4. *Everest and Jennings Mono-Drive Wheelchair.* One model of a motorized wheelchair (Fig. 11) manufactured by the E & J Corporation of Los Angeles, California, was evaluated. The units are powered by a 12-volt storage battery. The battery drives a Parvalux DC motor with a speed reducer. The motor which drives the single powered wheel by means of a chain is controlled by a handle containing switches in series to alter both motor polarity and voltage. The handle is mounted (left or right) on a steering column which provides directional control. Axial twist of the handgrip mounted on the steering column provides two forward and one reverse speeds; turns are made by rotating the handle in the horizontal plane toward the right for right turns and to the left for left turns.

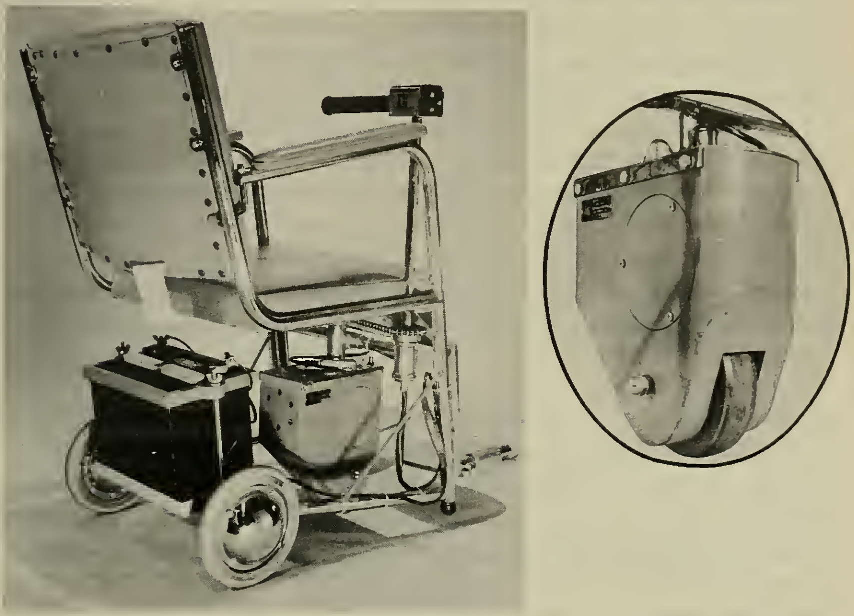

Figure 11. The principal features of Everest & Jennings Mono-Drive Wheelchair are the side-mounted control, chain drive, single forward drive wheel, and 12-volt storage battery.

The chair is of cantilever construction with a solid foam padded seat and back. It can be disassembled for storage. A battery charger is supplied with the unit.

Evaluation of this chair consisted of the following:

a. A comparison between the Mono-Drive and the Power Drive chair, another E & J wheelchair powered by two 6-volt batteries which drive two DC Parvalux motors linked to the wheel by belts. This comparison was drawn in terms of the criteria employed for Automotive Wheelchairs, VAPC, July 1, 1957, listed as follows:

(1) Speed—Must be adjustable to a low of 1 m.p.h.

(2) Obstacle Climb—Must be able to mount and cross a 1-in. obstacle.

(3) Ramp Climb—Must ascend and descend 10 percent slope at safe speeds.

(4) Dimensions—Must conform to VA Specification No. 7043400b for Wheelchair, Folding.

(5) Maneuverable—Must be easily maneuvered.

(6) Design—Motor units and battery carriers should not be permanently mounted to the chair.

(7) Power Supply—Power supply must be sufficient to operate for a normal day's use and be rechargeable overnight.

(8) Other—Any other pertinent observations.

b. A biomechanical analysis of the Mono–Drive's operation with respect to safety and ease of operation. The evaluation program revealed several advantages afforded by the Mono-Drive chair. Entry or exit from either side is facilitated by the removable armrests. Despite its relatively small overall dimensions, seating space is quite ample. It is substantially lighter than the Power Drive chair (120 lb. versus 161 lb.), and it requires a smaller turning space (41 in. versus 54 in.).

However, there are several significant disadvantages which have been reported to the manufacturer for correction prior to qualification testing.

5. Cetrone Contoured Support Belt. A sacroiliac belt that is designed to be worn around the pelvis below the level of the anterior iliac spines is being evaluated (Fig. 12). The belt purports to afford maximum support to the sacroiliac joint and according to the developer, eliminates the need for cumbersome corsets. The belt is designed to apply strong lateral forces tending to compress the ilia. In so doing, tension is reduced on the ligaments supporting the lower lumbar vertebrae and those between the sacrum and the ilium. These ligaments, the developer states, are the sites of injury in low back pain.

The device features two anti-slipping pads which prevent the belt from riding up and reducing its effectiveness. The belt, constructed of top grain cowhide leather with a two-pronged buckle, comes in three sizes. At present, two subjects have been fitted with the Contoured Support Belt.

C. Evaluation (Techniques)

None.

V. TESTING

A. Specifications Compliance

1. SACH Feet. During this period, the annual test program for molded SACH feet was initiated. To date, tests have been completed on SACH feet submitted by the Otto Bock and Kingsley Companies.

The products of both these manufacturers met the minimum standards set forth in current VA specifications. Although the Kingsley SACH Foot met the functional standards to the fullest extent, X-ray examination revealed that the belting is attached to the keel by means of a profusion of badly placed staples. While having little immediate consequence on the results of the functional tests, this condition may reduce the life of the product.

The Bock SACH Foot met the specifications requirements despite several marginal minor discrepancies. Flexure resistance was very close to the high resistance limits in one size 8 foot, and in another size 8 foot, heel compression was minimally adequate.

2. Stump Socks. Five samples of wool leg stump socks were tested for compliance with specifications in accordance with our interim check program scheduled midway between our annual compliance tests. All samples of stump socks submitted by the Bennington, Accurate, McCann, Ohio Willow Wood, and Knit Rite companies were tested in accordance with procedures listed in Invitation No. 66–1 dated April 14, 1965. All samples conformed to current requirements indicating an improvement in the general quality of stump sock production in this country.

3. Upper-Extremity Components. Annual compliance tests were conducted on three upper-extremity components: a. Sierra Internal Elbow, b. Sierra Voluntary Closing Hook, and c. Sierra Voluntary Opening Hand. The performance of all three units met the requirements set forth in the specifications.

B. Materials

1. Luperco Catalysts. The catalyst most commonly used in polyester lamination techniques is Luperco ATC, a product of Wallace & Tiernan, Inc. ATC is a benzoyl peroxide paste compounded with tricresyl phosphate. Two difficulties attendant on the use of ATC are that it separates (Fig. 13) and that it cannot be shipped by mail under existing fire hazard regulations.

More recently, Wallace & Tiernan produced two benzoyl peroxides with somewhat different formulations. The first, Luperco ANS–50, is a nonseparating form of benzoyl peroxide dispersed in butylbenzoyl phthalate and the second, Luperco AFR, is a fire resistant and non-separating paste form of benzoyl peroxide dispersed in an inert organic plasticizer. This special feature of AFR allows small quantities to be sent through the mail without an I.C.C. yellow label.

The three Luperco pastes, products of Lucidol Division, Wallace & Tiernan, Inc., 1740 Military Road, Buffalo, New York 14240, were evaluated to determine curing patterns, skin reactivity, and general utility.

To determine the effects of the catalysts uninfluenced by factors related to reinforcing materials, pigments, and laminating techniques, a two-phase study was based on comparisons of samples with these factors controlled. In

Phase A, gel times were recorded for potted samples of resins with varying concentrations of catalyst and promoter. In Phase B, polyester laminates were made over a tapered wood mandrel, 5 in. in diameter at one end, tapering to 3 in. at the other end, and 12 in. long with 4 nylon stockinets, and gel time was recorded.

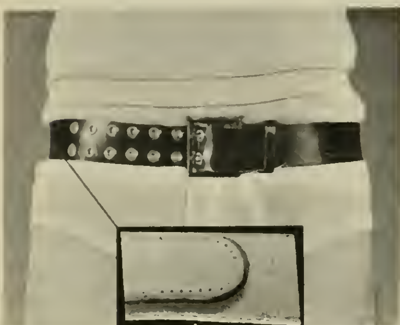

FIGURE 12. The Cetrone Contoured Support Belt, designed for relief of low back pain, worn by patient with the internal contoured sections applying lateral force to the depression below the iliac crest. Inset shows details of the "contour," a section of leather sewn on the inside of the belt.

FIGURE 13. A jar of Luperco ATC showing the typical separation of constituents which takes place during storage.

The controlling factors included:

a. The use of Laminac No. 4110 in all samples.

b. Only concentrations of 1, 2, and 3 percent of each test catalyst (ATC, ANS–50, AFR) were used.

c. Each set of tests in Phase A and B was done once with 8 drops of promoter No. 3 and once again with 16 drops of promoter No. 3.

d. The same experimenter performed all tests.

The results of these analyses are summarized below:

a. *Gel Time.* Potted samples (Phase A) of 1 percent ATC, ANS–50, and AFR gelled respectively in 99 minutes, 126 minutes, and 172 minutes with 8 drops of promoter. However, when the concentration of catalyst was increased to 2 percent, both the ATC and ANS–50 gelled in 76 minutes, while AFR required only 52 minutes under the same conditions. At a 3 percent concentration, gel times were 50 minutes for ATC, 30 minutes for ANS–50, and 35 minutes for AFR. In all potted samples, doubling the amount of promoter to 16 drops halved the gel time.

In Phase B, employing polyester laminates and 8 drops of promoter, similar results were obtained. At a 1 percent concentration of catalyst, gel times were 70 minutes for ATC, 111 minutes for ANS–50, and 149 min-

utes for AFR. At a 2 percent concentration, the ATC required 38 minutes, the ANS–50 required 47 minutes, and AFR required 63 minutes to gel. These differences were reduced to insignificance when a 3 percent concentration of catalyst was used; gel times were 24 minutes for ATC, 33 minutes for ANS–50, and 39 minutes for AFR. Doubling the amount of promoter to 16 drops cut all three gel times by approximately 60 percent.

b. *Skin Reactions.* Ten normal subjects participated in patch tests to observe skin reaction to intimate contact with polyester laminates made with nylon stockinet, 2 percent concentration of each of the three types of catalyst, and 8 drops of promoter No. 3. Three disks, each made with different catalysts, were taped to the volar aspect of the forearm. After 24 hours the patches were removed; all reactions were negative.

The following summarizes the relative advantages and disadvantages of each catalyst in laminates employing 3 percent concentrations of catalyst, 8 drops of promoter No. 3, and nylon stockinet:

Catalyst	Gel time, minutes	Homogeneity	Relative shipping costs
ATC	24 Good	Poor, separating	High.
ANS–50	33 Fair	Good, non-separating	High.
AFR	39 Fair	Good, non-separating	Low.

The sole advantage of ATC is its relatively rapid gel time under normal working conditions. However, the fact that it separates may reduce its advantage. ANS–50 does not separate but it requires more time to gel than ATC. Neither of these two catalysts meets the I.C.C. requirements for mail shipment and therefore procurement costs are somewhat higher. AFR on the other hand does not separate, and it can be shipped through the mails.

Although it requires proportionately more time to gel than the other two products, used in concentrations of 2 or 3 percent gel time differences are negligible.

If gel time is not a factor, AFR seems to be the catalyst of choice. The selection of the other catalysts on the basis of gel time must be balanced by shipping costs and time delay in working. Attempts to reduce gel time of AFR by the simple expedient of increasing the number of drops of promoter is not recommended because of the possibility of discoloration.

2. *Polypropylene Reinforcing Fabric For Lamination.* In general prosthetics-orthotics practice, nylon stockinet is replacing Fiberglas as the reinforcing material for polyester lamination. While the laminates obtained with nylon stockinet and polyester resin are adequate as regards strength-

for-weight characteristics, lighter laminates would be preferred. Fiberglas epoxy laminations are now considered to have the highest strength-weight ratios, but their use in prosthetics and orthotics has been limited by some objectionable characteristics of the constituent materials.

Polypropylene is a thermoplastic polymer obtained from propylene gas, a hydrocarbon by-product of the alkylate refining process of gasoline. Polypropylene fiber is produced by The Vectra Company, Odenton, Maryland.

This material is being evaluated by comparisons with nylon and Fiberglas as reinforcing materials. Although polypropylene fabric has not previously been used in prosthetic applications, it appears to be superior to Fiberglas as the reinforcing material in molded boats.

Sample polyester laminates will be prepared under as nearly identical conditions as possible. One-third of them will employ nylon stockinet, one-third Fiberglas, and one-third polypropylene. Another group of samples will be laminated with epoxy resins, again one-third nylon reinforced, one-third Fiberglas, and one-third polypropylene. The six types of specimens will be compared in terms of process requirements, weight, workability, and resistances to tension, bending, impact, and fatigue.

VI. OPERATIONS REPORT FOR FIRST HALF, FISCAL YEAR 1966

The data in this section reflect the prosthetic and orthotic services provided for veteran beneficiaries during the first half of Fiscal Year (F.Y.) 1966 by the VAPC's Orthopedic Shoe Service and Prosthetics-Orthotics Service.

A. The Orthopedic Shoe Service

As shown in Table 7, an increase of 136 in the number of beneficiaries on the rolls of the Orthopedic Shoe Service had no appreciable effect on the total workload.

However, the issuance of protective footwear (rubbers or overshoes) during the first half of F.Y. 1966 increased markedly. Fifty-eight pairs of rubbers and 103 pairs of overshoes were issued at a cost of $3,360.

In the first half of F.Y. 1966, eighty-eight worn clinic lasts were duplicated at a cost of $836.

B. The Prosthetics-Orthotics Service

The distribution of surgical supports and elastic hosiery is the responsibility of the Orthotic Components Unit of the Prefabricated Appliances Section, Prosthetics-Orthotics Service. Tables 8 and 9 show that the issuance of these items remains relatively constant.

TABLE 7.—*Numbers and Costs of Shoes in VAPC National Orthopedic Shoe Program*

	Fiscal Year				
	1962	1963	1964	1965	First Half F.Y. 1966
Benef. on rolls	9, 344	9, 681	10, 021	10, 322	10, 458
New shoes, prs.	7, 465	7, 249	7, 317	7, 336	3, 622
Prs. of new shoes issued per benef. on rolls per yr.	. 80	. 75	. 73	. 71	[a] . 69
Cost, $	394, 222	387, 757	440, 536	442, 641	198, 892
Repaired shoes, prs.	8, 660	9, 716	9, 487	9, 422	5, 286
Prs. of shoes repaired per benef. on rolls per yr.	. 93	1. 00+	. 95	. 91	[a] 1. 01
Cost, $	92, 514	97, 778	93, 520	130, 916	55, 143
Total cost, $	486, 736	485, 535	534, 056	573, 557	254, 035

[a] Projected for full fiscal year.

As reported in a previous bulletin (BPR 10–3 Spring 1965), the average cost fluctuation is due primarily to changes in the internal accounting procedures.

During the first half of F.Y. 1966, the Prosthetics Components Unit of the Prefabricated Appliances Section distributed 47 additional Hydra-Cadence Above-Knee Systems. The number of beneficiaries receiving this unit since the inception of the distribution program is 1,302.

During the report period, 460 Hydra-Cadence (H-C) units were replaced. In addition, 354 H-C cosmetic covers and 75 H-C feet were replaced. The manufacturer repaired 154 units at no cost; 273 units were repaired and converted at a cost of $40,373. VAPC technicians did minor repairs to 108 units at a cost of $1,060.

The issuance of 68 Mauch HYDRAULIK swing-control units during the report period has brought the total number of wearers of this device to 152. In the same period 150 DuPaCo units were issued increasing the total number of wearers to 256. Twenty-seven Mauch and 27 DuPaCo units were replaced during the report period; many of these were units that had been issued during the clinical application study. DuPaCo repaired 10 units at a cost of $309. Nineteen Mauch units were repaired at a cost of $1,183.

VA Orthopedic Shops received 16 above-knee and 12 below-knee temporary prosthesis units. Seven above-knee and 9 below-knee temporary prosthesis units were sent to commercial limb facilities. Forty-seven SACH

TABLE 8.—*Numbers and Costs in the VAPC Surgical Support Distribution Program*

Issuance Channel	F.Y. 1963		F.Y. 1964		F.Y. 1965		First Half F.Y. 1966	
	No.	Cost ($)	No.	Cost ($)	No.	Cost ($)	No.	Cost ($)
Individuals	2, 162	11, 568	2, 434	12, 901	2, 482	16, 691	1, 234	6. 127
VA Orthopedic Shops	3, 098	14, 239	3, 995	18, 091	3, 722	18, 033	3, 815	9. 118
Total	5, 260	25, 807	6, 429	30, 992	6, 204	34, 724	5, 049	15, 245
Average Cost, $		4. 89		4. 82		5. 60		3. 03

TABLE 9.—*Numbers and Costs in the VAPC Elastic Hosiery Distribution Program*

Issuance Channel	F.Y. 1963		F.Y. 1964		F.Y. 1965		First Half F.Y. 1966	
	No.	Cost ($)	No.	Cost ($)	No.	Cost ($)	No.	Cost ($)
Individuals	5, 806	33, 385	9, 989	47, 460	9, 554	62, 672	4, 212	20, 851
VA Orthopedic Shops	6, 598	37, 938	12, 258	55, 130	11, 049	56, 950	6, 929	30, 277
Total	12, 404	71, 323	22, 247	102, 590	20, 603	119, 622	11, 141	51, 128
Average cost, $		5. 75		4. 61		5. 80		4. 59

feet were issued to VA Orthopedic Shops and 14 to commercial limb facilities for use in temporary prostheses.

During the first half of F.Y. 1966, the Limb and Brace Section delivered 36 above-knee prostheses; twenty-one of these utilized total contact sockets. Only 19 of 68 below-knee prostheses delivered were of the patellar-tendon-bearing (PTB) type. In this same period, 13 above-knee and 16 below-knee temporary prostheses were delivered. Twenty-five upper-extremity protheses were fabricated and delivered to beneficiaries.

Orthotists of the section deliverd 33 leg-thigh and 58 leg braces in addition to 28 spinal braces and 815 arch supports.

The VAPC Clinic Team held 29 meetings during the first half of F.Y. 1966. The 68 beneficiaries seen were referred by 13 field stations.

C. Special Service for Vietnamese Wounded

In the Fall of 1965, 56 paralyzed Vietnamese veterans were brought to the Veterans Administration Hospital at Castle Point, New York for medical treatment. Shortly thereafter the VA Prosthetics Center was authorized to provide the orthotic services necessary to rehabilitate these men.

On November 23, 1965 selected staff members attended a special clinic meeting held at the VAH, Castle Point, N.Y. The group consisted of Anthony Staros, Director, VAPC; Dr. Edward Peizer, Chief, Bioengineering Research Service; William J. McIlmurray, Chief, Prosthetics-Orthotics Service; Dominick Bonarrigo, Acting Chief, Orthopedic Shoe Service; and Werner Greenbaum, Chief, Limb and Brace Section, P-O Service. The clinic was conducted by Dr. Emilio Ejercito, Chief, PM&R Service of VAH, Castle Point with consultation by Dr. Alfred Ebel, Chief, PM&R Service of the VAH, Bronx, N.Y.

At this session, it was decided to concentrate first on the relatively simple cases and expedite their rehabilitation. Ten cases were selected on the criteria that minimal bracing would make early ambulation possible. Prescriptions were developed for these men at this time. Of the 10, 2 would wear braces unilaterally; the other 8 would be bilateral brace wearers. Most of the components used in the braces were prefabricated; the bars were of aluminum. These braces were delivered before the end of December 1965. Typical braces are shown in the accompanying photographs (Fig. 14, 15, and 16). General characteristics and diagnoses as taken from the charts of these 10 men and the braces made are given in Tables 10, 11, and 12.

FIGURE 14. Case No. 8 wearing lateral bar leg braces.

FIGURE 15. Case No. 34 wearing a right lateral bar leg brace and a left lateral bar leg-thigh brace.

Figure 16. Case No. 43 wearing conventional medial-lateral bar leg-thigh braces.

Table 10.—*General Characteristics of Paraplegic Vietnamese Subjects*

Subj. No.	Age	Date of injury	Marital status	Height	Weight, lb.	Occupation	Service rank
2	34	8/26/63	M	5′0″	95	Merchant	Corporal
4	35	6/11/64	M	5′1″	119	Farmer	Corporal
6	29	12/26/64	S	4′10″	88	Student	Sergeant
8	22	9/23/65	M	5′0″	95	Laundryman	Pvt., 2/c
34	28	12/15/64	M	5′1″	100	Bus Driver	Private
36	29	11/ 7/64	S	5′5″	90	Student	2nd Lt.
39	38	11/11/64	M	5′0″	126½	Farmer	Sergeant
43	24	5/18/64	M	5′0″	103½	Farmer	Private
45	21	4/19/64	S	5′7″	88	Painter	Private
49	33	1/31/65	M	5′4″	119	Farmer	Corporal

Table 11.—*Diagnoses of Paralyzed Vietnamese Subjects*

Subj. No.	Diagnosis
2	Myeloneuropathy, chronic, traumatic, probably due to injury of L–4, clinically complete motor wise below L–3 and sensory wise below L–3, and the posterior columns in T–12 for touch and pain. Has loss of function of both lower extremities and of sphincters of bowel and bladder.
4	Myeloneuropathy, chronic, traumatic, due to fracture of C–6, clinically incomplete, with signs of a Brown Sequard's lesion and radicolopathy of the left upper extremity, manifested by good motor function of the left lower extremity by about 50% and loss of function of the left upper extremity, 100%.
6	Myeloneuropathy, chronic, traumatic, due to fracture of L–1–2, clinically complete at this level with sacral sparing manifested by loss of function of left lower extremities estimated about 50% loss of function of the right lower extremities, 100% below the knee, and loss of function of sphincters of bowel and bladder.
8	Myeloneuropathy, chronic, traumatic, due presumably to cord concussion approximately around L–3 without obvious bony injuries and manifested by partial cauda equina lesion between L–3 and S–2 as demonstrated by lower motor neuron signs, by the upper motor neuron lesion below S–2, loss of function of both lower extremities, 100% at ankles and below the ankles and 100% loss of function of sphincter of bowel and bladder.
34	Myeloneuropathy, chronic, traumatic, with probable injury to L–1 clinically below L–1 on the left and L–2 on the right and loss of function of both lower extremities, 100% for the left, 100% for the right at and below the ankle and approximately 50% for the right knee and hip and 100% loss of sphincters of bowel and bladder.
36	Myeloneuropathy, chronic, traumatic, due to injury of L–1 and L–2, clinically complete at L–2 with loss of sensation of both lower extremities and of sphincters of bowel and bladder.
39	1. Cranial-Cerebral injury, due to bullet wound, right temporal region with subsequent left hemiparesis. 2. Corneal opacification, O.D. 3. Bilateral pterygium.

TABLE 11.—*Diagnoses of Paralyzed Vietnamese Subjects*—Continued

Subj. No.	Diagnosis
43	Myelopathy, chronic, traumatic, due to fracture of L–1. Clinically incomplete. Loss of function in the lower extremities, changes in segments below L–3 on the left and less so on the right. Motor impairment extends probably to S–1 but seems to be absent below that level: in brief, this is a partial cauda equina lesion.
45	1. Myeloneuropathy, chronic, traumatic, due to fracture of L–2, clinically incomplete at that level motor wise, but complete sensory wise with loss of function of both lower extremities and of sphincters of bowel and bladder. 2. Penile-scrotal fistula. 3. Bladder stones.
49	Myeloneuropathy, chronic, traumatic, due to bullet wound in L–3 and L–4, clinically complete below L–2, on the left and T–12–L–1 on the right with loss of function of the lower extremities and of sphincters of bowel and bladder.

Table 12.—*Orthopedic Appliance Prescriptions*

Subj. No.	Prescription
2	Left leg brace with single lateral bar and spring-loaded ankle joint. Right leg brace with single lateral bar and spring-loaded ankle joint.
4	Left leg brace with medial and lateral bars and positive equinus stop.
6	Left leg brace with single lateral bar and spring-loaded ankle joint. Right leg brace with single lateral bar and spring-loaded ankle joint.
8	Left leg brace with single lateral bar and spring-loaded ankle joint. Right leg brace with single lateral bar and spring-loaded ankle joint.
34	Left leg-thigh brace with single lateral bar with ring lock and solid stop ankle joint. Right leg brace with single lateral bar and solid stop ankle joint.
36	Left leg-thigh brace with medial and lateral bars with ring lock and positive equinus stop. Right leg-thigh brace with medial and lateral bars with ring lock and positive equinus stop.
39	Left leg brace with single medial bar and positive equinus stop.
43	Left leg-thigh brace with medial and lateral bars with ring lock and spring-loaded ankle. Right leg-thigh brace with medial and lateral bars with ring lock and free-motion ankle.
45	Left leg-thigh brace with medial and lateral bars with ring lock and spring-loaded ankle. Right leg-thigh brace with medial and lateral bars with ring lock and spring-loaded ankle.
49	Left leg brace with single medial bar, lateral "T" strap and spring-loaded ankle. Right leg brace with single medial bar, lateral "T" strap and spring-loaded ankle.

On several subsequent visits made to the hospital before the end of the year, prescriptions were developed for braces for an additional 14 men. The prescriptions were prepared by Dr. Ejercito by consultation with Mr. McIlmurray or Mr. Greenbaum.

HIGHLIGHTS OF VA CONTRACTUAL RESEARCH PROGRAM

PROSTHETICS

John O. Esslinger, M.D.
Birmingham, Michigan

This project continued its research on the attachment of an external prosthesis by semiburied attachment and of plugging the amputated bone to increase tolerance to end-weight bearing. If present dog experiments are successful, the technique eventually may have application for human amputees.

Dr. Esslinger's procedures with dogs consist of:

1. Continuing study of acceptability of different materials.
2. Continuing study of the effects of plugging amputated bone with Teflon or in combination with other materials, using multiple designs.
3. Use of semiburied implants alone or attached to the end of bone plugs by which direct end bearing can be attained.
4. Ultimately, developing external prosthesis for successful cases in methods 2 and 3, above.

Gilmatic, Northridge, California
Gilbert M. Motis

Since this project is a relatively new one under the sponsorship of the Prosthetic and Sensory Aids Service, it may be well to list the areas of investigation conducted at Gilmatic in a long-range plan.

1. Development of a completely electrically powered prosthesis, including prehension, wrist rotation, elbow flexion, and shoulder motion, to simulate near normal operation, from body or muscle-controlled sources. Components for each area of motion would be separately developed but coordinated with those for other motions, so that units may be provided to accommodate amputees at any level. Initial emphasis is on wrist rotation.
2. Development of a series of body or muscle-operated switching or transducer-type control systems. Each system would provide control from an independent source so that multiple controls may be produced without undue interference.
3. Research with a view to providing a variable "rate" in the control system to permit the amputee to select speed of motion and hence "time into working position" of the prosthesis in all important areas of operation.
4. Further development of a mechanical feedback sensing device.

Mauch Laboratories, Inc., Dayton, Ohio
Hans A. Mauch

In preparation for a clinical application study to be conducted by the Veterans Administration, assembly has been taking place of a number of Model A, Swing and Stance Control Systems.

The design of a pre-production prototype of a hydraulic ankle control unit has been completed with very satisfactory results. It is hoped that castings and component parts will soon become available for the assembly of the first pre-production unit.

The project is studying the use of a myo-electric control unit produced by the University of New Brunswick for the voluntary actuation of swing and stance control. Also under study is the use of ultrasonic energy for control of the prosthesis. Reflex-like control with voluntary override has always been considered more desirable than mere reliance on a signal like pressure on the heel, or even a sophisticated control like that in the Model A. One problem has been use of remaining stump muscles without unduly complicating the fitting process.

National Academy of Sciences-National Research Council
Washington, D.C.

A significant undertaking of the Committee on Prosthetics Research and Development during this period has been the preparation of a draft manual on immediate post-surgical management. Various research teams and others involved in immediate post-surgical fitting will meet in Chicago on July 13–14, 1966 with the prosthetics education groups to discuss plans for the conduct of educational programs to introduce the techniques on a wider scale. After trial at a pilot school, the manual probably will be further revised for wider publication.

Panel meetings on upper- and lower-extremity prosthetic fitting and on lower-extremity orthotics were held during the past few months.

The Committee on Prosthetic-Orthotic Education held its annual meeting in Washington, D.C. on April 7, 1966. Reports by the several subcommittees which had been active throughout the year were presented and discussed.

New York University, New York
Renato Contini

Dynamic pressure data are being collected and reduced. Peak pressure readings are being analyzed to determine how much variation can be expected for a variety of test conditions, e.g., variations at a particular site on a day-to-day basis. During successive runs, a gradual change in peak pressures had been noticed. It had been suggested that the Micro Systems transducers would produce such results if certain units were temperature, sensitive rather than fully temperature-compensated as claimed. Bench tests of the trans-

ducers revealed that a small change in temperature did produce a detectable proportional shift in electrical balance. Temperature recordings by a thermistor at the transducer location inside the socket indicated a paradoxical *drop* in temperature of a few degrees when the amputee began activity, presumably as a result of ventilation from pumping action causing evaporation of prespiration, rather than an increase in temperature from muscular activity.

The project also continued to follow the maintenance experience of 12 wearers of the Henschke-Mauch "HYDRAULIK" Model A, Swing and Stance Control System.

Northwestern University, Chicago,Illinois
Clinton L. Compere, M.D.

Two reports prepared by this project are published elsewhere in this issue: Lift Tab Positioning Jig and Adult Center Control Hook.

Development activities continued in both the upper- and lower-extremity fields. Project personnel continued to participate in panel sessions of the CPRD and in teaching assignments at Northwestern University.

An electric power assist, fitted to a bilateral amputee with a left above-elbow amputation and a right shoulder disarticulation, has been functioning well after some three months use. A long above-elbow amputee and a forequarter amputee will also be fitted. Further work is being done to make the unit more compact.

Lightweight flexible polyester laminate retaining sockets have been used with hemipelvectomy cases when the prosthesis is removed, apparently with good results.

Under the supervision of Dr. Compere, the Seattle techniques of immediate post-surgical fitting have been tried, with very successful results. The Northwestern University adjustable pylon has been adapted to the immediate post-surgical technique by the addition of expanded stainless steel straps for incorporation into the cast and by provision for a push-button quick disconnect between cast and pylon.

University of California at Los Angeles
Biotechnology Laboratory
John Lyman, Ph.D.

Elsewhere in this issue will be found the UCLA report on the Heidelberg pneumatic prosthesis. The project has also submitted its report on The Evaluation of the Northwestern University Attitudinally-Controlled Electric Elbow for possible publication in a future issue of the Bulletin. In process is the rewriting of a technical report on the French electric hand.

The project is exploring minor surgical methods for developing new body control sites, and experimental results are being evaluated. A report sum-

marizing the tentative criteria for externally powered prostheses is being prepared.

University of California at San Francisco and Berkeley
Charles W. Radcliffe and Howard D. Eberhart

Testing of the pneumatic swing-control units has continued at the Biomechanics Laboratory and in cooperation with the VA Prosthetics Center, New York. After correction of the original design to provide proper piston-cylinder clearance these units have proved to be effective and durable units requiring a minimum of adjustment over extended periods of use.

Thirty metal knee-shank assemblies for use with the pneumatic swing-control units have been delivered by the Hosmer Corporation. The metal assemblies will replace the present wooden knee-shank units which are currently being amputee-tested in San Francisco. These units are also adaptable to use by knee-disarticulation cases and spare units are available for this purpose.

The four-bar linkage polycentric knee has been completely redesigned to improve its range of motion, swing-phase control, and cosmesis when used with a piston-cylinder pneumatic swing control. The redesign made extensive use of a new mathematical method for linkage design developed by the biomechanics study group.

A study of the biomechanics of joint motion in the lower-extremity is being carried out in two parts: design of an instrumentation system for precise measurement of relative motion components at the ankle, knee, and hip joints and development of mathematical methods of synthesis of three-dimensional linkages which could be used as orthotic devices. The mathematical methods are of general engineering interest and two papers on these methods have been accepted for presentation at the Second ASME Conference on Mechanisms, November 1966.

An improved SACH foot was designed by an engineering graduate student and included provision for inversion-eversion, ankle rotation. and adjustable heel height. A simplified model incorporating inversion-eversion and adjustable heel height was constructed and tested. Based upon results of these tests, a second model has been constructed which incorporated an inclined inversion-eversion axis at 30 deg. to correspond to the keel angle of the SACH foot. Preliminary tests indicate that the inclination of the inversion-eversion axis may minimize the need for an ankle rotator in some cases.

VA Hospital, Seattle, Washington
Ernest M. Burgess, M.D.

Results of this project on immediate post-surgical prosthetic fitting continue to be highly gratifying.

Dr. Burgess presented a paper at the Annual Meeting of the American Academy of Orthopaedic Surgeons in January 1966. In connection with a panel meeting of the Committee on Prosthetics Research and Development program, Dr. Marian Weiss of Poland and other surgeons and research workers visited the project and reviewed a series of cases.

A film describing the technique has been completed and will shortly become available on a loan basis. The project has also worked closely with the Executive Director of the Committee on Prosthetics Research and Development in the drafting of a comprehensive manual covering the various aspects of immediate post-surgical management.

Dr. Burgess and his staff will participate in plans for the teaching of the technique by the three universities offering prosthetics educational programs, namely New York University, Northwestern University, and the University of California at Los Angeles.

SENSORY AIDS

Fabrication of Obstacle Detectors for the Blind
Bionic Instruments, Inc., Bala Cynwyd, Pennsylvania
J. Malvern Benjamin, Jr. and D. Ridgeley Bolgiano

Work continues on the cane-mounted electronic aid for the blind mentioned and illustrated in BPR 10–4 Fall 1965, the preceding issue of this Bulletin. The feature presenting the most difficulty to the researchers is detection of curbs or step-downs several steps ahead of mechanical contact of the cane tip. Solution of this problem through optical means has proved sufficiently difficult that one channel of the three in the cane is reserved exclusively for this function. The recent advent of semiconductor injection lasers operable at room temperatures promises to allow for significant advances in reaching a solution to the curb detection problem. Gallium arsenide laser-like material of slightly different composition has been used in a noncoherent or "nonlasing" mode for about two years as a much brighter source than previously available flash lamps, but was only marginally bright enough on poor targets, especially at the oblique angles needed for early warning of curbs.

Along with staff members in the contractor's organization, Dr. Murphy and Mr. Freiberger of the VA Research and Development Division, PSAS, have been actively seeking out appropriate lasers for use as light sources in the cane. Government, University, and industrial sources have been very cooperative. Because of the recency of the laser's development, its superb light production capabilities, and the relatively simple associated optics and electronics, some of the manufacturers of the material, though sympathetic to the needs of the blind, have been guarded in revealing certain trade secrets or even coming to reasonable sales agreements. A tiny chip of

specially doped [a] gallium arsenide, about 4 x 4 x 10 mil rectangular prisms, cleaved to length on the natural cleavage planes of the material, comprise the actual laser. The cleaved surfaces serve as the "mirrors" at the ends of the laser, reflecting the infrared radiation back and forth in a resonant cavity. Fed with an appropriate pulse of current through mounting electrodes, this laser emits an extremely bright flash, concentrated in a narrow cone easily captured by a small lens. It is believed this source will greatly improve the functioning of optical mobility aids for the blind, such as the cane under development at Bionic Instruments, Inc.

Spelled-Speech for Automatic Readers Usable by the Blind
Metfessel Laboratories, Inc., Los Angeles, California
Milton Metfessel, Ph. D. and Constance Lovell, Ph. D.

As indicated in the report on the Sixth Reading Machine Conference, published in this issue of the Bulletin, Professor Metfessel is currently engaged in reducing his long experience with spelled-speech to a set of rules usable by any researcher to produce a set of spelled-speech sounds. This information will be included in a final report on this project scheduled for publication about July 1966.

Research on Audible Outputs of Reading Machines for the Blind
Haskins Laboratories, Inc., New York, N.Y.
Franklin S. Cooper, Ph. D. and Jane Gaitenby

The aim of the research at Haskins Laboratories has been and still is to find out how to generate acceptable speech in the best and simplest way. Such speech generation is required because of a fundamental assumption that only spoken English will prove acceptable for a truly high-performance reading machine. The man-made speech will be produced on the basis of letter or word knowledge taken from the printed page by optical character recognition equipment.

Activities at the Laboratories continue in several areas including refinement of rules for synthesis, study of speech cues in various contexts, intonation and stress, voice recording for compiled-speech reference words, word-by-word synthesis from control signals (re-formed speech), studies of the rules of prosody, and plans for field tests with compiled speech.

Technical details of much of the research in speech at Haskins Laboratories may be found in the four issues of their Status Report on Speech Research, a publication that first appeared in January 1965.

[a] Addition of a small amount of some other substance.

Output Characteristics and Construction of an Interim Word-Reading Machine

Haskins Laboratories, Inc., New York, N.Y.
Franklin S. Cooper, Ph. D. and Paul Brubaker

At a demonstration of this machine, compiled speech was automatically produced from a locally prepared "Teletypesetter" tape used as "input." The demonstration proved the workability of the concept.

During the period of this fixed-price contract (1957–1966), there have been extraordinary advances both in machine technology and in understanding of speech synthesis. The original concept of stringing prerecorded words together using the hardware first contemplated, today seems a largely obsolete approach. For this reason, steps are being taken to terminate this contract and to transfer equipment and knowledge resulting from the work to the other VA contract with Haskins Laboratories.

The Development and Evaluation of a Personal Reading Machine for the Blind

Mauch Laboratories, Inc., Dayton, Ohio
Hans A. Mauch and Glendon C. Smith

Since the last issue of the Bulletin, work at Mauch Laboratories has been concentrated on the evaluation of the Visotactor B, construction of a Multicolumn Visotactor, evaluation of the Visotoner, and initiation of construction of 4 new Visotactors B, 6 Visotoners, and 10 Colineators. Messrs. Mauch and Smith presented several papers at the Sixth Reading Machine Conference (reported elsewhere in this issue of the Bulletin). Mr. Smith presented a paper, "A Family of Portable Reading Machines for the Blind," at the 50th Anniversary Meeting of the Optical Society of America, and Mr. Mauch appeared on network television in the "I've Got a Secret" program, March 21, 1966.

During January 1966, Miss Reinicke, the blind subject in Dayton, began reading a book of mystery stories, *Alfred Hitchcock's Ghostly Gallery,* with the Visotactor B and Colineator. After several hours of practice, she became accustomed to the new type style and the techniques involved in reading a book. The first test was taken from page 13. Miss Reinicke read for twenty minutes at an average speed, including line change time, of 7.0 words per minute.

On February 3, 1966, Miss Reinicke read page 33 of the Hitchcock book at an average rate of 8.0 words per minute and on February 15, 1966, she read page 47 at an average rate of 8.1 words per minute. On February 17, the Visotactor B used by Miss Reinicke was modified to produce less energetic tactile stimuli. The voltage applied to the stimulator coils was reduced from 6.0 volts to 4.5 volts. Miss Reinicke reported that the reduced stimulator voltage in the Visotactor B seems to allow reading for longer periods without fatigue. On March 1, 1966 and March 22, 1966, Miss

Reinicke read from her book at average rates, including line change time, of 6.9 and 6.4 words per minute, respectively.

The completed Multicolumn Visotactor was first tested on January 26, 1966 and performed satisfactorily. The tactile display is somewhat confusing at first for a person accustomed to a single column device. In a short time, however, the user begins to recognize letters and shapes.

Further experiments with the Multicolumn Visotactor prototype indicated that the circular cells first used in the photocell array result in a tactile pattern sufficiently different from that produced by narrow, tall cells from the same printed character to confuse a person accustomed to the narrow, tall cells. To eliminate this effect as a variable in later testing, the array of circular cells first used in the Multicolumn Visotactor will be replaced with an array of 24 rectangular cells each .010 in. wide and .050 in. high. Drawings and mask negatives for such an array were made and copper masks were etched. Several arrays have already been completed.

Mr. Harvey Lauer, a VA staff member at Hines, Illinois, originally trained on the VA-Battelle Optophone, demonstrated the Visotoner at the Sixth Technical Session on Reading Machines, Washington, D.C., January 1966, and indicated that he was already using it to read labels on cans and boxes in addition to letters, signatures, paper money, bank statements, etc. He had carried the Visotoner and its battery in the leather case to a supermarket where he scanned the labels of possible purchases. Mr. Lauer also stated that rotating the optical barrel to correct for italics did in fact make italics readable.

The special manufactured parts for the construction of 4 Visotactors B, 6 Visotoners, 10 Colineators, 10 battery chargers, 20 rechargeable batteries, 10 spare lamp assemblies, and 5 spare optical barrel assemblies were ordered during January 1966. The gages needed for manufacturing and inspection were ordered also. Many of the temporary assembly tools used at Mauch Laboratories were improved, and several new tools were made.

The photocell arrays used in earlier prototypes were made by cutting standard photocell substrates with a diamond wheel to fit the array barrel. Considerable savings in labor would result by having an alumina substrate manufactured in the final shape needed. Three manufacturers of high alumina ceramics were requested to bid on making the photocell substrate to our specifications.

During March 1966, the electronic parts for the Visotactor and Visotoner prototypes were ordered. Most of the manufacturing and inspection gages were received and accepted by Mauch Laboratories. The aluminum castings for the Visotactor-Visotoner handles and bases and the Colineator cross slides were completed during March and given to the parts manufacturer for the required machining.

Determination of Performance Attainable with the Battelle Optophone

American Center for Research in Blindness and Rehabilitation, Newton, Massachusetts
Leo H. Riley, M.D.

The two subjects in this program reported on in BPR 10–4 have temporarily withdrawn, one because of illness, the other as a result of obtaining short-term employment in another city. The tests were thus brought to a halt. Project operations are now being revised to allow for the training of new subjects in the evenings and on weekends. These more convenient hours for instruction should provide for a more stable retention of subjects in the program.

Evaluation of Ultrasonic Aid for the Blind

American Center for Research in Blindness and Rehabilitation, Newton, Massachusetts
Leo H. Riley, M.D. and Gunther Weil, Ph. D.

Since October 1965, a total of fourteen subjects have been trained and tested in the use of the Kay guidance device. Progress of the work has been hampered by instrument failures necessitating the return of several instruments to England for replacement and by the loss of four subjects who dropped out of the program during the Christmas recess.

Project training began with an introduction to the physical structure of the device and to principles of operation, emphasizing the carrying, packing, and unpacking of the device. Elementary ranging experiments then followed, and by December 1965, all subjects were estimating the distance to a wall as subjects moved back from the wall as well as estimating distances to a moving trainer. All subjects also practiced in determining range limits for the device.

Four subjects who dropped the program during the Christmas recess were replaced in January 1966. The new subjects were put through intensive ranging procedures. By January, the subjects were attempting to maintain a constant distance between themselves and a moving trainer, and evaluation of their static ranging skills was carried out.

By February, dynamic ranging skills were evaluated and training on static scanning was begun. Subjects were trained to locate the trainer in a 180-deg. arc, to estimate the range, and then to locate the trainer by touch. Following this, subjects were trained to scan on a 360-deg. pattern with the trainer moving in and out of the arc at varying distances. This task involved both scanning and ranging skills.

In object location experiments, the subjects were required to determine the number of objects in a room and find each object in turn. Training in indoor navigation involved stairs and doors.

With the advent of spring, outdoor training commenced, and indoor testing was completed. Emphasis was placed on obstacle detection, safety,

finding of landmarks, and the following of paths. A film was made of the subjects using the device. Subjects were tested in these areas and the data are being analyzed.

A paper on this research was presented at St. Dunstan's International Conference on Sensory Devices for the Blind, June 1966.

Development of Test Procedures for Evaluation of Binaural Hearing Aids
Northwestern University, Evanston, Illinois
Raymond Carhart, Ph. D.

One line of current investigation has been the study of the influence of head movement on monaural and binaural reception of speech materials. Monaural and binaural reception of speech materials in the presence of competition was tested under: (1) a condition in which the human head was held immobile by mechanical means, (2) a condition in which the listener could move his head slightly, and (3) a condition in which the subject was permitted substantial head movement. The competing signal in the first part consisted of a second talker reading sentences, while speech spectrum noise served as the competing signal in the second part of the experiment. Results revealed no important differences between the condition for which the head was held immobile and the condition analogous to that used in previous work under this contract, namely, the situation permitting slight head movement. Moreover, substantial head movement reduced the head shadow effect only slightly. Also, binaural listening was consistently superior to the best monaural situation regardless of whether the head was held immobile or permitted slight or substantial movement.

A second investigation deals with hearing aids from three manufacturers with different degrees of harmonic distortion. Two instruments of each hearing aid from each manufacturer have been purchased and tested repeatedly with various inputs and gain settings. In one instance, sharp differences in harmonic distortion were found between two instruments of the same model and manufacture. There is some indication that the differences observed may be attributable to the insert receiver of the hearing aids, at least for the particular instruments purchased. Various procedures for measuring harmonic distortion are being tested in an effort to determine the effect of the test condition on the amount of harmonic distortion observed in the hearing aid.

The performance of hearing-impaired persons while receiving speech through these different hearing aids is currently being studied. Speech reception thresholds, speech discrimination in quiet, and speech discrimination in the presence of competing signals are being tested. Monaural direct, monaural indirect, and binaural listening conditions are employed when testing speech discrimination in the presence of competition.

Electroacoustic Characteristics of Hearing Aids
Houston Speech and Hearing Center, Houston, Texas
James Jerger, Ph. D.

Recent research on this project has shown that physical differences between hearing aids can be reflected by a suitable sentence intelligibility test. In order to achieve such results it was necessary to make the listening task complex, to control for learning, and to minimize error by repeating the same materials several times. When this test was employed to evaluate individual hearing-impaired subjects, the rank-ordering of aids was reasonably constant. In other words, the best hearing aid for *any* subject was apparently the best hearing aid for *every* subject, at least in the small selection of aids tested.

Although this test consistently differentiated among hearing aids differing widely in their acoustic characteristics, previous experiments have indicated that the magnitude of the differences can be altered appreciably by simply varying the nature of the instruction given to the listener. The contractor proposes, therefore, to continue development on a new battery of speech materials that will discriminate among hearing aids, but that will also be resistant to the kinds of subject variability that have been previously demonstrated.

For this purpose, a new sentence intelligibility test has been developed. The message sets for this test consist of artificial or synthetic sentences of actual English words. The sentences were constructed on the basis of specific linguistic rules. In this way, both the length and relative informational content of each sentence in a message set can be precisely controlled. The use of artificial sentences in place of actual English sentences permits the construction of many equivalent forms. The ease with which these materials can be generated provides a new and exciting technique for manipulating several variables of hearing aid performance on the same listeners.

The Effects of Distortion on Hearing-Aid Performance
Auditory Research Laboratory, VA Hospital, Washington, D.C.
Roger N. Kasten, Ph. D. and Stephen H. Lotterman, Ph. D.

For many audiologists, the only method by which they may determine the electroacoustic characteristics of a given hearing aid is to consult the manufacturer's specifications for that instrument. To determine the accuracy and reliability of these published characteristics, a representative group of eyeglass, behind-the-ear, and body-type aids were selected with 15 instruments of each model being tested. All testing was accomplished in a miniature anechoic chamber, and with each instrument, measurements were made of full-on gain, gain versus frequency response at the full-on gain setting, and total harmonic distortion at approximately 12 discrete frequency points.

The results revealed a great deal of variability between the manufacturer's specifications and the actual performance of the groups of aids. The vari-

ability within groups was also quite large. For most models, there was a wide range of gain values and distortion levels among the 15 aids of the group. The gain versus frequency tracings often revealed markedly different patterns.

These results indicate that the actual aid tested should be issued as in VA practice, or that a follow-up visit should ensure that an externally purchased aid of the same make and model tested is actually appropriate for the hearing aid user.

Intermodulation test tapes prepared at the National Bureau of Standards are being used with a group of hard-of-hearing subjects to gain knowledge of the psychoacoustic reaction to this particular form of equipment deficiency.

NOTES AND NEWS

ORIENTATION PROGRAM FOR VIETNAMESE MEDICAL AND PARAMEDICAL PERSONNEL

Described in the VAPC Semiannual Report of this issue are some of the Vietnamese military personnel who received paralyzing wounds in their home country and who were transported to the U.S. Veterans Administration Hospital at Castle Point, New York for treatment. The Veterans Administration has assumed responsibility for the rehabilitation of these people. Moreover, the Veterans Administration has undertaken training programs for the Vietnamese military medical and paramedical personnel who accompanied these patients to the United States.

Among these programs of training is a fourteen-session orientation on prosthetics and orthotics planned and conducted by professional personnel of the Research and Development Division of the Prosthetic and Sensory Aids Service and the VA Prosthetics Center. Vietnamese physicians, nurses, and technicians at Castle Point are receiving weekly lectures and demonstrations on principles of prosthetic and orthotic restoration, prosthetic socket design and fabrication requirements, alignment considerations, orthotic appliance construction and fitting procedures, component selection, shoe fabrication and modification, performance evaluation, training, and checkout. It is expected that more detailed educational programs will be developed later for some of these people, either here in the United States or in Vietnam on their return there.

RENATO CONTINI OF NYU RECEIVES HUMAN FACTORS AWARD

Mr. Renato Contini of New York University was awarded the first Outstanding Service award offered by the Human Factors Division of the American Society for Mechanical Engineers. The award was presented at the Human Factors Division's first annual conference in Washington, D.C., March 28–29, 1966. Commander M. Scott Carpenter, famed astronaut and aquanaut, was the featured speaker.

Mr. Contini is one of the founders of the Human Factors Division, ASME, and has served the division over the years as secretary, chairman, and member of its Executive Committee. Since its inception the activities of an NYU prosthetics project under contract with the VA have been coordinated by Mr. Contini. In addition, he has served as the first president of the Human Factors Society, chairman of the Second Engineering Founda-

tion Conference on Engineering in Medicine, cochairman of the First Engineering Foundation Conference on Engineering in Medicine, chairman of the American Society for Engineering Education Committee on Biomedical Engineering, and chairman of the Subcommittee on Engineering Interactions with Behavioral Sciences for the Engineers Joint Council Committee on Engineering Interactions with Medicine and Biology.

On the second day of the conference, Dr. E. F. Murphy, Chief, Research and Development Division of PSAS, chaired a session on government activities in biomechanics and described the VA's role in that area.

TRAINING COURSE FOR PROSTHETIC REPRESENTATIVES

The second of a series of intensive training courses for Prosthetic Representatives was conducted by the Prosthetic and Sensory Aids Service in its New York Offices from April 18 through April 29, 1966. Eighteen Prosthetic Representatives participated in this course.

The course emphasized principles and techniques to be used in the inspection and evaluation of artificial limbs. With this additional training the Prosthetic Representatives, who serve as Chiefs of Prosthetics Services, should be of even greater assistance to clinical personnel engaged in prosthetics restorations activities.

Similar courses are to be conducted in the Chicago area from June 6–17, 1966 and in San Francisco, October 24–November 4, 1966.

OPTICAL SOCIETY SESSION ON READING MACHINES FOR BLIND

At the Fiftieth Anniversary meeting of the Optical Society of America held in Washington, D.C., March 15–18, 1966, Dr. Eugene F. Murphy described the multiple approaches being undertaken to enable the blind to read independently. He pointed out that although a few blind persons are successfully using experimental portable models with limited capabilities, commercial production of reading machines is several years away. More sophisticated models using computers are foreseen within the next few years.

Many tasks of everyday life at home or on the job require deciphering only a few words, as on a label or address list, so high speed is not as important as ability of the blind person to do the job independently. The VA research program has developed several prototypes of portable machines to translate shapes of letters into audible or tactile signals which a blind person can learn to recognize slowly after long training.

For longer passages, higher speeds are necessary, so a much more complicated and expensive machine must recognize the individual letters. Commercial machines now can read credit card vouchers or checks, but most of these handle only "cooperative" numerals or letters printed in known locations and special type styles. To aid a blind person, a reading machine

FIGURE 1. Participants in training course for Prosthetic Representatives held in New York, April 18–29, 1966. Kneeling (left to right): Karl B. Pfirrmann, VAH, Cincinnati, Ohio; William J. Gosselin, VAH, Manchester, New Hamp.; James D. Johnson, VAH, Louisville, Ky.; Kenneth A. Weyrauch, VAH, Buffalo, N.Y.; Bartolome Lopategui, VAC, San Juan, P.R. Standing (left to right): James A. Donovan, VAH, Atlanta, Ga.; James Cohen, VA Prosthetics Center, N.Y.; James B. King, VAH, Wilmington, Del.; Griffith C. Blair, VARO, St. Petersburg, Fla.; Hugh T. Smyth, VARO, Pittsburgh, Penn.; Henry C. Bass, VARO, Baltimore, Md.; Joseph R. Mirabella, VAH, Newington, Conn.; Frank Lombano, VAH, Batavia, N.Y.; Edward P. Tomashewski, VAH (West Side), Chicago, Ill.; Terrence Kolpackoff, Jr., VAOPC, Brooklyn, N.Y.; Edward Whiteside, VAH, Syracuse, N.Y.; Michael MacDonagh, VAH, Wilkes-Barre, Penn.; Blaine H. Whorton, VARO, Columbia, So. Car.; Julius Feig, VARO, New York, N.Y.

must recognize many of the common type fonts used in books, magazines, newspapers, and typewriters.

The problems of transmitting the recognized letters to the brain of the blind person probably are even more serious, Dr. Murphy explained. Though the computer industry is making progress on multifont character recognizers able to cope with misaligned print and to communicate with other machines, there is relatively little commercial interest in spoken output, of long messages.

Braille or other tactile outputs, so necessary for the severely handicapped deaf-blind, are even less likely to be developed commercially.

The Veterans Administration has convened a series of six conferences on reading machines since 1954. These have brought together engineers,

psychologists, linguists, and rehabilitation experts, a majority from outside the Veterans Administration program.

The research program in reading devices aims at a broad spectrum. Designs range from simple translators placing great demands on the blind user to translate slowly the non-speechlike code output through various compromises, to far more complex and expensive machinery with output pronounced as words allowing greater speed with negligible training. The first category should be portable and suitable for individual ownership, while the large machines will only be practicable for libraries. Research toward a potentially useful compromise using a special "spelled-speech" output was described to the Optical Society of America during the same session by Glendon C. Smith of Mauch Laboratories, Dayton, Ohio, one of the VA contractors.

VAPC DIRECTOR TO PARTICIPATE IN INTERNATIONAL 10th WORLD CONGRESS

Mr. Anthony Staros, Director of the VA Prosthetics Center in New York City, will participate in the Tenth World Congress of the International Society for the Rehabilitation of the Disabled to be held in Wiesbaden, Germany, September 11–17, 1966. In addition to presenting a paper at the conference, Mr. Staros will instruct at the seminar planned in conjunction with and immediately preceding the World Congress.

At the seminar, which will be held in Münster, September 5–10, 1966, Mr. Staros is scheduled to lecture on *Modelling and Fitting Techniques for AK Stumps* and *Hydraulic and Pneumatic Gait Control,* under the main topic of "Prosthetic Care for the Lower Extremity." Other topics to be covered in Münster are: The Amputee and His Stump, Prosthesis Technique for the Upper Extremity, Orthotic Technique and Dysmelia Care, and Orthopedic-Technical Research.

The Wiesbaden conference will include some of the following topics: Rehabilitation and Social Legislation; Opening the Doors to Education-Prosthetics, Orthotics, and Technical Aids; Basic Requirements for the Supply of Prosthetics in Emerging Countries; The Role of Different Professional Groups in Promoting Rehabilitation in the Emerging Countries, etc.

ORIENTATION DAY FOR RESIDENTS

As reported in the BPR 10–3 Spring 1965 issue, the Prosthetic and Sensory Aids Service is continuing its policy of conducting an annual orientation day in prosthetics and orthotics for residents in the Metropolitan New York area. Admittedly no substitute for the more intensive courses offered by New York University, UCLA, and Northwestern University, the one-day orientation session nevertheless has apparently been enthusiastically received by residents in orthopedics and in physical medicine and rehabilitation.

For the orientation program planned for May 4, 1966, some 40 residents have already enrolled.

We again commend this medium to VA field stations as an effective means of covering the highlights of prosthetics and orthotics for residents, both in VA and in community hospitals.

AWARD FOR DR. FRED LEONARD

We are pleased to report that Dr. Fred Leonard of the U.S. Army Medical Biomechanical Research Laboratory recently received the Exceptional Civilian Service Award. Dr. Leonard has long been associated with this laboratory and its predecessor, the Army Prosthetics Research Laboratory.

Brig. Gen. Colin F. Vorder Bruegge, MC Commanding General of the Army Medical R & D Command, conferred the award on behalf of the Secretary of the Army. He praised Dr. Leonard's outstanding contributions to medical science, noting in particular his development of tissue adhesives for non-suture closure of wounds which resulted in more tissue-receptive adhesives.

Dr. Leonard has been the recipient of many awards and decorations for his work in the prosthetics field. His present award cited his exceptional service in the broad planning and supervision of research programs under his direction. The citation read in part: "Dr. Leonard's personal drive and leadership resulted in the recent organization of physicians and physical scientists of the Walter Reed Committee on Surgical Implants. His contributions to, and his status in, the scientific world have earned him international recognition as an authority on the application of polymers to surgical implants."

"SIGHT SWITCH" AS AID FOR HANDICAPPED

The sight switch, which enables an individual to control various mechanical devices without the use of his hands or limbs, is seen as a possible aid for the severely handicapped.

Developed by Spaco Inc. while doing research for NASA's Marshall Space Flight Center, the switch was initially intended for use by astronauts during space flights. Realizing the vast potential uses of this device, NASA is encouraging its adoption by industry and for the handicapped. Along these lines, the developers have produced a motorized wheelchair employing these switches which allows the occupant to move forward or back or turn to either side by using his eye motions only. A wheelchair of this kind could give some paraplegics or stroke victims a degree of independence they could not otherwise attain.

Other uses of the sight switch that are being developed for the incapacitated are controlling a mechanical page turner, switching room lights on and off, controlling a TV or radio, adjusting room temperatures, raising or lowering a bed, and signaling for a nurse. Industry has plans for operating

industrial machines, control panels, and typewriter keyboards. Many more possibilities have yet to be explored.

The operation of the switch is accomplished by cylinder units mounted on each earpiece of eyeglass frames, and activation of the switch is governed by looking to the left or to the right. Each cylinder contains an infrared light source, transistor amplifier, sensitivity control, and an infrared sensor. Hearing aid-type wires lead from the rear of the cylinders to a belt-mounted or pocket battery pack and control relay. The key to the concept of activating the switch is the white of the eyeball which is a better reflector of infrared light than is the iris.

An absorbing film depicting the use of the switch with a wheelchair and other devices has been produced by the developers. The film is available for professional use and may be obtained by writing to the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama 35812.

HERTZ RENT-A-CAR FOR THE HANDICAPPED

In compliance with the President's Committee on Employment of the Handicapped, Hertz Rent-A-Car has made specially equipped cars available for rental to the handicapped. Outfitted with hand controls, at no additional charge, these cars can now be used by handicapped persons who drive for business or pleasure. To allow time for the installation and testing of the hand controls, a minimum of two days reservation is required when requesting a car. In addition, a valid driver's license must be presented at the time of rental. At the present time, these cars are obtainable in the following cities: Boston, Chicago, Dallas, Los Angeles, Miami, New York, San Francisco, and Washington, D.C. All cars must be returned to one of these cities.

MAUCH VISOTONER AND COLINEATOR DEMONSTRATED

On April 29, 1966, at the annual meeting of the President's Committee on Employment of the Handicapped in Washington, Mr. Harvey Lauer, a blind Braille Therapist at VA Hospital, Hines, Illinois, demonstrated his ability to use, at a rewarding reading rate, the Mauch Visotoner and Colineator (Fig. 2) for a variety of tasks including proofreading material which a secretary had deliberately mistyped.

Dr. E. F. Murphy described the research activities on aids for the blind which are supported by the Prosthetic and Sensory Aids Service.

Other participants, most of whom have been informally cooperating with the Prosthetic and Sensory Aids Service or with the NAS–NRC program, demonstrated other new devices which potentially may aid in employment of the handicapped.

FIGURE 2. Harvey Lauer operates Mauch Visotoner and Colineator at annual meeting of the President's Committee on Employment of the Handicapped, as Dr. E. F. Murphy of PSAS, Veterans Administration, assists in the demonstration.

LOYAL E. APPLE HONORED

Mr. Loyal E. Apple, Chief of the Rehabilitation Center at Veterans Administration Hospital, Hines, Illinois, was chosen as the Outstanding Federal Supervisory Employee of the Year among 60,000 Federal employees in the Chicago Metropolitan area. Mr. Apple was selected for this honor at the Tenth Annual Federal Employee of the Year Awards Program on May 12, sponsored by the Chicago Federal Executive Board and The Federal Personnel Council of Chicago.

In 11 years he has achieved national recognition as an authority on rehabilitation of the blind, been hailed as one of 1960's ten top young men by the National Junior Chamber of Commerce, and become a living symbol of the ability of a blind person to develop initiative, independence, and self-reliance. He supervises 28 other instructors and therapists, has increased the regular patient load of his center from 28 to 34, trains additional specialists—including the staff of a new center for the west coast—and is making improvements in the familiar long cane.

Mr. Apple was blinded in a training accident at Fort Lewis, Washington, in 1955 while serving in the Army. He has a B.A. degree from William Jewell College, Liberty, Missouri, where he was graduated from in 1952. He took his rehabilitation training at Hines VA Hospital in 1956, then went on to become an expert in this work.

REPORTED ABROAD [a]

PROSTHETIC HAND DISCOVERED ON 2000-YEAR-OLD EGYPTIAN MUMMY

During a routine radiological check in the Gulbenkian Museum of Oriental Art, England, a prosthesis was discovered on a 2000-year-old mummy (Fig. 1).

The mummy, which was taken to the Dryburn Hospital in Durham for a series of tomographs, revealed that an artificial hand with fabric fingers was fitted over a deformed forearm. It seems that the ancient Egyptians also knew how to make and fit artificial limbs.

IMPROVED "CYBERNETIC" FOREARM

Purporting to incorporate most of the advantages and eliminating some of the disadvantages of the Soviet and British arms, Dr. Walter Horn, Director of the Institute for Advanced Prosthetics at the Ospedale Maggiore, Vercelli, Italy, has designed an improved "cybernetic" prosthesis.

One of the shortcomings of the previous models was interruption of contact between skin and electromyographic signal electrode pickups. Dr. Horn said this is overcome in the present model by a very high input impedance amplifier. This also dispenses with the need to prepare the skin before applying the prosthesis by ensuring good function even when contact between skin and electrodes is poor.

Another drawback in previous models is interference from spurious signals or "noise." Patients wearing the Soviet model were unable to approach fluorescent lamps, electric typewriters, or radio sets without the risk of the prosthesis failing to operate. In reference to his prothesis, Dr. Horn stated, "Thanks to the high-rejection mode of my model, the patient can use it in an electric power station if he wants."

The normal hand, in the natural physiological process, responds almost instantaneously to directives from the brain. The prosthesis, however, passes through two stages for this process: Electronic amplification of the "balanced" signal reaching the electrodes on the patient's stump and a servo action for finger positioning and "feel." The servo action employs two feedback mechanisms. The hand, opening as it moves quickly towards an object, does so as the result of velocity transmission of power (or transduced EMG signal) from a small electric motor to a system of levers. The

[a] Based chiefly on translations by Dr. Gabriel Rosenkranz, Medical Consultant to the VA Prosthetics Center.

patient then closes his hand. Switchover to torque transmission takes place as soon as the closing fingers come up against resistance. A torque multiplier then provides pinch or grasp force with a maximum development of 18 lb., although, according to Dr. Horn, 10 to 15 lb. is usually sufficient.

Motor feed is cut off automatically when the hand is closed and no further force is exerted. This reduces battery drain on the six miniature silver zinc cells (ordinary flashlight batteries can be used).

The prosthetic hand, which weighs only slightly more than the normal hand, is designed in three sizes: for children, for teenagers, and for adults. Dr. Horn feels that it will be particularly suitable for phocomelics and bilateral amputees because a "mental dependence on a surviving hand has not been able to develop."

FIGURE 1. Photograph shows artificial left hand found on mummy. Note that wrist of sound right hand was cut away to enable the prosthesis to be removed (University of Durham, Gulbenkian Museum of Oriental Art and Archaeology).

RECENT PATENTS [a]

Aid for Blind Switchboard Attendant: Robert F. Schuyler, assignor to Bell Telephone Laboratories, Inc., a corporation of New York. A manual switchboard for use by a blind attendant. It contains audio generators for generating distinctly different tones which are responsive to incoming calls. Each tone corresponds to a different row on the switchboard, and these tones are received in a headset which is used by the attendant. (Patent No. 3,234,337, Feb. 8, 1966; filed July 20, 1962, Serial No. 211,272; 5 claims.)

Abdominal Belt: Wendolyn F. Gakle. An abdominal belt designed with a plurality of individual, adjustable straps or bands that encircle the body to enable desired compressibility of the body member. The belt is made of a resilient material and is easily adjustable by bands in front of the garment. (Patent No. 3,213, 856, Oct. 26, 1965; filed May 9, 1963, Serial No. 279,240; 3 claims.)

Apparatus for Transferring Invalids: Frederick Albert Batty and Peter Lawrence Batty. A wheeled chair which facilitates the movement of an invalid from place to place such as from a bed and a bathtub. (Patent No. 3,220,575, Nov. 30, 1965; filed Sept. 6, 1963, Serial No. 307,150; claims priority, application Great Britain, Sept. 6, 1962, 34,143/62; 6 claims.)

Arm Slings: Charles H. Groesbeck. An easily removable sling that suspends from the shoulder. It can be adjusted easily for different physical sizes and positions; does not soil or require laundering as does a cloth sling. The inventor claims it is inexpensive to manufacture, convenient and dependable in operation, and capable of performing properly after long periods of operation. (Patent No. 3,215,158, Nov. 2, 1965; filed Oct. 31, 1962, Serial No. 234,459; 2 claims.)

Audiometric Headset: Willard B. Hargrave. An audiometric headset which can be used in making tests in the presence of ambient noise without resorting to a soundproof booth. The sound producing apparatus resides within the dome in an interfitted and replaceable manner without need for securing devices separate from the members themselves. (Patent No. 3,220,505, Nov. 30, 1965; filed Apr. 1, 1964, Serial No. 356,676; 7 claims.)

Cervical Collar: Nicholas C. Connelly, assignor to S. H. Camp & Company, a corporation of Michigan. A cervical collar that is supposed to provide improved head support and greater stability than previously obtained with existing collar constructions. It is also designed to prevent "rocking" of the collar related to the patient's shoulder and neck which permits considerable head movement. (Patent No. 3,220,406, Nov. 30, 1965; filed Dec. 17, 1962, Serial No. 245,155; 9 claims.)

Chair for Non-Ambulatory Persons: Charles R. Bockus. Having a number of adjustable parts to render it more comfortable, this chair can be converted from a wheelchair to a comfort chair. The seat includes an upright post to prevent the patient from sliding off. The chair is adjustable for people who are either very short or very tall. The back is adjustable at top and bottom and can be moved forward or back as well

[a] Patents may be ordered by number from the Commissioner of Patents, Washington, D. C. 20231, at 50 cents each.

as tilted in various angles. The armrests and footrests are also movable and may be adjusted to suit the patient's requirements. (Patent No. 3,216,738, Nov. 9, 1965; filed May 1, 1963, Serial No. 277,316; 6 claims.)

Electrical Hearing Aid: Jacob de Groot and Johannes Matheus Gerardus Maria Kaanders, assignors to North American Philips Company, Inc., a corporation of Delaware. A hearing aid to be carried behind the ear housing a receiver on supporting brackets and a microphone, a battery housing, and an amplifier on a chassis plate located in the housing. The battery housing and the two supporting brackets with the chassis plate are structurally integral with each other. A switch is provided which occupies very little space in the hearing aid housing. (Patent No. 3,221,111, Nov. 30, 1965; filed Nov. 23, 1962, Serial No. 239,597; claims priority, application Germany, Dec. 16, 1961, N 13,260, N 13,261; 3 claims.)

Crutches: Mogens H. Kiehn, assignor to Kiehn Products Company, a corporation of Illinois. A crutch construction to be used as a walking aid for handicapped or disabled individuals. This crutch employs devices for support of the torso as well as the support obtained from the armpits. The crutch is simple in design and according to the inventor, inexpensive to produce. (Patent No. 3,213,870, Oct. 26, 1965; filed Feb. 21, 1963, Serial No. 260,234; 4 claims.)

Electrical Hearing Aid: Werner Güttner, Clemens Starke, and Franz Sapara, assignors to Siemens-Reiniger-Werke Aktiengesellschaft, a corporation of Germany. An electrical hearing aid to be worn in the back of the ear comprising a housing containing the microphone, amplifier with regulating elements, battery, and receiver. It has a hook-shaped carrier portion, free of electrical components, connected with the housing and attachable to the upper part of the auricle. (Patent No. 3,209,080, Sept. 28, 1965; filed June 29, 1961, Serial No. 120,640; claims priority, application Germany, May 12, 1961, S 73,924; 7 claims.)

Hand-Operated Extension for Pedal Type Controls for Automotive Vehicle: Paul V. Malloy. A hand-operated control device for operating the pedal-like control of an automotive vehicle. An elongated member is attached to the control pedal at one end and contains an attachment device at the other end adapted to be grasped along with the steering wheel. (Patent No. 3,226,997, Jan. 4, 1966; filed May 3, 1965, Serial No. 452,784; 20 claims.)

Hearing Aid: Stuart G. McCarrell and Harry A. Wayne, assignors to Beltone Electronics Corp., a corporation of Illinois. An improved hearing aid completely contained in a composite unitary structure that is to be worn in the external ear of the user. The microphone and receiver of the assembly are positioned relatively close to one another, enabling greater miniaturization, but are acoustically isolated from each other for maximum gain and power free from acoustical and vibratory feedback. (Patent No. 3,209,082, Sept. 28, 1965; original application May 27, 1957, Serial No. 661,628, now Patent No. 3,061,689, dated Oct. 30, 1962. Divided and this application Aug. 16, 1962, Serial No. 198,694; 1 claim.)

Hyperextension Back Brace: Nicholas C. Connelly, assignor to S. H. Camp & Company, a corporation of Michigan. A brace employing side pieces which anchor in the trochanteric region and support a padded rigid pelvic band that widely spreads the pressures applied to the pelvic region across the lower torso and pelvic basin. The inventor states that the improved distribution of pressures produced by the brace results in greater comfort to the patient without sacrificing needed support. (Patent No. 3,220,407, Nov. 30, 1965; filed Oct. 8, 1962, Serial No. 229,039; 1 claim.)

Invalid Elevator: William M. Booth, assignor to Welded Products, Inc., a corporation of Michigan. Consists of a frame with vertically positioned parallelogram supports

connected to the frame, a platform suspended between the parallelogram supports and a power drive means to raise and lower the platform. (Patent No. 3,229,788, Jan. 18, 1966; filed June 25, 1963, Serial No. 290,429; 9 claims.)

Invalid Chair: Floyd B. Wamsley, assignor to Helen E. Beart. A chair to be used as a wheelchair in association with a bed and a toilet. It is compact and readily manipulated within the confines of dwellings or hospitals. (Patent No. 3,215,469, Nov. 2, 1965; filed Mar. 5, 1962, Serial No. 177,570; 6 claims.)

Invalid Lift: Victor R. Hildemann, assignor to Ted Hoyer & Company, Inc., a corporation of Wisconsin. An invalid lift that is small, lightweight, and when not in use can be folded for easy transportation in the rear seat or trunk of a car. The lift can be adjusted while supporting the patient to allow the attendent to guide it through narrow doorways and passageways. (Patent No. 3,222,029, Dec. 7, 1965; filed Jan. 20, 1964, Serial No. 338,909; 6 claims.)

Method and Apparatus for Testing Hearing: Arnold Phillip Towne, assignor by mesne assignments of one-third each to E. J. Mosher and M. P. Sullivan of Houston and Harry J. Mosser of Alice, Texas. A testing apparatus that provides an objective hearing test that will test sensation, frequency, and perception simultaneously. At the same time, it tests the coordinated hearing of both ears of a subject, and as well each ear independently of each other. (Patent No. 3,221,100, Nov. 30, 1965; continuation of application Serial No. 38,964, June 27, 1960. This application July 17, 1964, Serial No. 384,577; 24 claims.)

Method for Adhesively Securing Together Skin and Other Soft Tissue and Bone: Milton C. Cobey, assignor to the President and Directors of Georgetown University, Washington, D.C. A method of adhesively securing severed tissue together, such as bone, cartilage, tendon, and soft tissue, by providing an adhesive composition which can set rapidly in the presence of moisture after coating upon or injection into the site of the damaged tissue. (Patent No. 3,223,083, Dec. 14, 1965; filed Sept. 9, 1960, Serial No. 54,914; 6 claims.)

Multipurpose Invalid Chair: Mattie P. Hubbard. A chair constructed and arranged to provide compactness and convenience. It is made with an upholstered seat cushion which serves to cover and conceal a commode opening. In addition to offering rest-room facilities, it includes a detachable and swingable tray which can be used for eating or writing. Also, the chair has a rack for a towel or washcloth, and a handle-bar on the back for pushing. The cabinet-type base of the chair contains side cabinets for storage of soap, toothpaste, medicine, toilet tissue, etc. At the bottom, there is a projectable and retractable slide that can be used as a footrest. (Patent No. 3,213,467, Oct. 26, 1965; filed Nov. 26, 1962, Serial No. 240,036; 2 claims.)

Orthopedic Apparatus Having an Improved Joint Construction: Candido Reyes, Madrid, Spain. A long-leg brace with joint construction of a new design. (Patent No. 3,230,952, Jan. 25, 1966; filed Mar. 5, 1963, Serial No. 262,932; claims priority, application Spain, Mar. 8, 1962, 275,299; 8 claims.)

Orthopedic Cervical Brace: Robert C. Blair, Jr. A rather simple and low cost cervical brace that can be easily adjusted and fitted to a patient without requiring the services of an expert fitter. The major components are readily removable for laundering and easily assembled again. Considerable flexibility of adjustment for fitting a variety of patients with different angular positions of the head is another feature of this brace. (Patent No. 3,224,439, Dec. 21, 1965; filed Mar. 28, 1963, Serial No. 268,621; 7 claims.)

Reading Aid for the Blind: John G. Linvill. An apparatus for converting an optical image to a vibratory image which may be sensed tactually. It consists of a plurality of separate piezoelectric vibratory reeds disposed in an array and means for vibrating each reed with an amplitude representative of the light from a different region of the image. (Patent No. 3,229,387, Jan. 18, 1966; filed Jan. 14, 1964, Serial No. 337,618; 8 claims.)

Safety Crutch: Richard J. Frank. An arm embracing cane-type crutch with rigid cuffs that encircle the forearm securely. The cuffs are releasable when desired. The inventor also states that structural failure of the crutch is unlikely because all the parts are so related and secured so as to prevent such failure regardless of weight of patient or how crutch is used. (Patent No. 3,213,869, Oct. 26, 1965; filed Feb. 27, 1964, Serial No. 347,922; 1 claim.)

Self-Feeding, Mouth-Controlled Eating Device: Antal Gratzer. An eating device for people whose hands and arms are impaired. It consists of a horizontally disposed rotatable tray with means for holding variable eating dish combinations. It is used for mouth-controlled, self feeding. (Patent No. 3,228,536, Jan. 11, 1966; filed Nov. 1, 1963, Serial No. 320,743; 8 claims.)

Stair Climbing Chair: Robert C. Grier, Jr. A wheelchair capable of being adapted to ascend and descend ordinary stairways without the use of special equipment. During ascent or descent, the chair is controlled by the occupant. (Patent No. 3, 226,128, Dec. 28, 1965; filed Sept. 9, 1963, Serial No. 307,430; 3 claims.)

Stair Climbing Invalid Carriages: Richard Appenrodt, Benefeld, Germany. A carriage comprising a chair, endless tracks on each side of the chair with track guiding wheels, and an electrical control circuit for operation of guiding wheels. (Patent No. 3,231,036, Jan. 25, 1966; filed May 11, 1962, Serial No. 194,136, Claims priority, application Germany, May 15, 1961, A 37,437; 14 claims.)

Stair Climbing Wheel Chair: Harold L. Kemm. A chair controlled and propelled solely by the occupant and adapted to ascend and descend, without an attendant, stairs and similar obstructions. Propulsion may also be obtained by self-contained power units such as battery-powered motors. Varying stair dimensions, with automatic compensation for such dimensions, can be negotiated by this chair according to the inventor. Also, the chair is said to be lightweight, economical to manufacture, adaptable to a folding construction, and easily transported. (Patent No. 3,214,184, Oct. 26, 1965; filed Sept. 26, 1963, Serial No. 311,694; 9 claims.)

Stair-Climbing Wheel Chair: Philip E. Massie. A foldable, occupant driven, stair-climbing wheelchair that turns on stair landings. It contains controls for changing the angle of the chair, a drive wheel on each side to support the rear of the chair, a retractable stair traction means on each side for engaging steps, etc. (Patent No. 3,227,465, Jan. 4, 1966; filed Dec. 28, 1962, Serial No. 248,104; 21 claims.)

Stair-Climbing Wheel Chair: James D. Thackery. A wheelchair adapted to be manipulated by the occupant up a flight of stair treads or over curbs. (Patent No. 3,215,446, Nov. 2, 1965; filed Aug. 9, 1963, Serial No. 301,026; 6 claims.)

Vehicle and Deformable Wheel Therefor: Robert W. McKinley. A single passenger vehicle capable of negotiating a series of steps as well as performing with ease and efficiency on flat surfaces. The chair can be manually operated, controlled, and propelled but allows for the economical inclusion of powered propulsion and control means. Also, this chair retains all the desirable structural and operating characteristics of conventional wheelchairs, such as light weight, collapsibility, carrying capacity, etc. (Patent No. 3,226,129, Dec. 28, 1965; filed Nov. 4, 1963, Serial No. 321,006: 7 claims.)

Wheel Chair Attachments: Ernest C. Loustaunau. Removable attachments for a wheelchair frame having a side wheel and open upward attachment sockets for mounting armrests, etc. Consists of a combination armrest and wheelguard assembly, and various other attachments. (Patent No. 3,231, 293, Jan. 25, 1966; filed June 1, 1964, Serial No. 371,525; 7 claims.)

Wheel Chair for Regular and Irregular Surface Travel: Paul P. Weyer. A wheelchair for traveling over regular or irregular surfaces by alternating running gears depending on the surface encountered. It is also foldable. (Patent No. 3,231,290, Jan. 25, 1966; filed Dec. 31, 1962, Serial No. 248,738; 3 claims.)

PUBLICATIONS OF INTEREST

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Experiences in Fitting Lower-Extremity Prostheses to Patients with Skin Disorders, E. Reese Owens; Inter-Clinic Infor. Bull., V(7):7–13, April 1966.

An Experimental Design for a Powered Arm Prosthesis, D. C. Simpson; Health Bull. (issued by the chief medical officer of the Scottish Home and Health Department), XXII(4):75–77, Oct. 1965.

Improving the End-Bearing Characteristics of Lower Extremity Amputation Stumps—A Preliminary Report, Alfred B. Swanson; Inter-Clinic Infor. Bull., V(5):1–7, Feb. 1966.

The I.N.A.I.L. Myoelectric B/E Prosthesis, Hannes Schmidl; Orthop. & Pros. Appl. J., 19(4):298–303, Dec. 1965.

Knee Disarticulation—A New Technique and a New Knee-Joint Mechanism, Robert Mazet, Jr. and Charles A. Hennessey; J. Bone & Joint Surg., 48–A(1):126–139, Jan. 1966.

The Münster-Type Below Elbow Socket, a Fabrication Technique, Hector W. Kay, Kevin A. Cody, George Hartmann, and Dominick E. Casella; Artificial Limbs, 9(2):4–25, Autumn 1965.

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The "Partial" Suction Socket, Milton J. Wilder; Inter-Clinic Infor. Bull., V(6): 1–3, March 1966.

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Prosthetic Rehabilitation of a Patient with Bilateral Hip-Flexion Contractures; Report of a Case, Justin Alexander and Gerald Herbison; Arch. of Phys. Med. & Rehab., 46(10):708–711, Oct. 1965.

Prosthesis Fitted After Bilateral Hip Disarticulation: Report of a Case, Horace W. Cosla, Sigmund Forster, and Joseph G. Benton. Arch. Phys. Med. & Rehab., 46(10):705–707, Oct. 1965.

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An Improved Splint for Treatment of the Carpal Tunnel Syndrome, Alfred R. A. Bengzon and Peter L. Eichman; Arch. Phys. Med. & Rehab., 47(2):84–87, Feb. 1966.

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The Present Status of Myo-Electric Control Systems in Patient Rehabilitation, R. N. Scott; Rehab. in Canada, 12:4–8, 1965–1966.

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CALENDAR OF EVENTS

International Society for Rehabilitation of the Disabled, Third International Seminar on Special Education, Germany, Sept. 7–10, 1966. (For information: Secretary General, Int. Soc. for Rehab. of the Disab., 219 E. 44th St., NYC 10017, U.S.A.)

International Society for Rehabilitation of the Disabled, Tenth World Congress, Rhein-Maine-Halle in Wiesbaden, Germany, Sept. 11–17, 1966. (For information: Secretary General, Int. Soc. for Rehab. of the Disab., 219 E. 44th St., NYC 10017, U.S.A.)

International Society for Rehabilitation of the Disabled, International Seminar on Vocational Assessment of the Disabled, Berlin, Germany, Sept. 18–21, 1966. (For information: Secretary General, Int. Soc. for Rehab. of the Disab., 219 E. 44th St., NYC 10017, U.S.A.)

American Occupational Therapy Association, Radisson Hotel, Minneapolis, Minn., Oct. 13–16, 1966.

AOPA National Assembly, Palm Springs Riviera Hotel, Palm Springs, Calif., Oct. 16–20, 1966.

Association of American Medical Colleges, Hilton Hotel, San Francisco, Calif., Oct. 20–26, 1966.

American Heart Association, Hotel Americana, New York, N.Y., Oct. 21–23, 1966.

Tenth Annual Human Factors Society Meeting, Disneyland Hotel, Anaheim, Calif., Nov. 1–4, 1966 (for members only).

Gerontological Society, Waldorf Astoria, New York, N.Y., Nov. 3–5, 1966. (Executive Director: Harry M. Rosen, MSSA, 4511 Forest Park Blvd., St. Louis, Mo. 63108.)

Association of Military Surgeons of the United States, Hilton Hotel, Washington, D.C., Nov. 8–10, 1966.

AHA Institute on Hospitals and Rehabilitation: Behavior and Staffing Conference, Hilton Hotel, San Francisco, Calif., Nov. 9–11, 1966.

American Medical Association, Clinical Meeting, Las Vegas, Nev., Nov. 27–30, 1966.

American Academy for Cerebral Palsy, Broadwater Beach Hotel, Biloxi-Gulfport, Miss., Nov. 29–Dec. 1, 1966 (Secretary: J. D. Russ, 1520 Louisiana Ave., New Orleans, La. 70115.)

American Association for the Advancement of Science, Washington, D.C., Dec. 26–30, 1966.

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